PROJECT RELAY COMMUNICATION PERFORMANCE

INTERIM REPORT NO. 1

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I. INTRODUCTION

The Relay I communication satellite was launched into orbit on 13 December 1963 at 2330 hours (GMT). Although a nearly perfect orbit was achieved, a malfunction in the regulator of the power supply for Transponder Number One caused the transponder to be turned on and off in a cyclic manner. Attempts to correct the difficulty by ground command were not successful initially. The heavy drain on the spacecraft batteries lowered the output voltage to unusable levels and no communication experiments could be performed. After about a week of relative inactivity for the satellite and correction of some difficulties in the command sequence, the battery voltage began to recover while Transponder Number One remained essentially off.

Finally, on January 3, 1963, during revolution 161, Transponder Number Two was successfully activated. The life of Relay I as a useful communication medium began with this revolution. Since that time and through March 8, 1963, the satellite has completed some 600 revolutions. Of these 105 have been devoted to communication experiments. All of the Project Relay ground and test stations have had an opportunity to participate to some extent in these experiments according to their capabilities. At least some experimental data has been received from all participants, although in general the quantity of data received by STL is much less than expected for the number of experiments performed.

These interim results are in consonance with the basic objectives of Project Relay. Stated once again, these are:

1. To advance the state of the art.
2. To develop knowledge and techniques applicable to an operational system.
3. To explore in particular the performance characteristics peculiar to an orbiting satellite.

These objectives have been kept in mind in examining the results of the communication experiments. The last objective has been of special interest because, in the absence of a moving vehicle in a space environment, the transmission of telephony and television via a microwave relay system is a familiar and well-understood problem.

The organization of this interim report on the communication performance of Relay I generally follows the format of the Project Relay Communications Experiment Plan, R1-0521. Reference is also occasionally made to the Project Relay System Requirements, R1-0000. Wideband performance, involving the transmission of television or 300 channel telephone multiplex, is considered first in Section II. There is more data in this area than for narrowband telephone transmission, principally because much of the data comes from the Relay test station at Nutley, N. J. (COMCON) which has only a wideband capability.

The narrowband system performance is considered in Section III. This section consists chiefly in the analysis of two-way telephone transmission with up to 12 channels. Some demonstration experiments involving teletype and facsimile transmission have also been conducted in the narrowband mode. Section IV summarizes both wideband and narrowband data taken to date, at least to the extent that it is available to STL. The final section presents such conclusions as can be drawn from this interim data with regard to system, and especially spacecraft, performance.

II. WIDEBAND COMMUNICATION EXPERIMENTS

II. A. 1. Insertion Gain and Insertion Gain Stability - Audio

This measurement is designed to determine the gain stability of the aural transmission associated with the television mode. An audio tone (at 1 kc from COMAND, COMBOD, and COMHIL) is transmitted. The tone should cause a 200 kc peak-to-peak deviation of the aural subcarrier. At the receiving station the level of the received tone is measured. The test can determine both the insertion gain stability and the insertion gain between ground stations. The objective for the Relay system is a 0 db insertion gain between points of zero relative level in the participating ground stations. Both incorrect deviations and incorrect amplifier gains can contribute to an insertion gain other than 0 db.

No reports have been received of insertion gain stability in the audio channel. However, reports have been received indicating insertion gain between stations on several passes. These results are tabulated in Table 1. The transmitted and received deviations are in fair agreement except for the COMBOD - COMHIL link on Rev 200. The actual insertion gain between stations cannot be estimated because the reported levels are not given at a point of zero relative level.

Table 1

Audio Channel Insertion Gain Measurements

	Transmit			Receive		
Rev	Station	Level	Deviation	Station	Level	Deviation
200	COMBOD		200 kc p-p	COMHIL	+3 dbm	56 kc p-p[1]
	COMAND	0 dbm[2]	32 kc p-p[3]	COMHIL	-5 dbm	23 kc p-p[1]
				COMBOD	-6 db[4]	36 kc p-p[5]
206	COMAND	0 dbm[2]	32 kc p-p[3]	COMBOD	-6 db[4]	36 kc p-p[5]
	COMAND	+10 dbm	100 kc p-p	COMBOD	+3 db[4]	100 kc p-p[5]
	COMHIL			COMBOD	+3 db[4]	100 kc p-p[5]
285	COMAND			COMHIL	+65 db	

Notes

1. Deviations for COMHIL on Rev 200 were calculated on the basis of a reference received level of +8 dbm for 100 kc p-p deviation.
2. COMAND transmitted levels are measured at the input to the diplexer.
3. Deviations for COMAND were calculated on the basis of a reference transmitted level of +10 dbm for 100 kc p-p deviation.
4. COMBOD levels are reported relative to a "typical" level.
5. COMBOD received deviations were calculated on the basis of an assumed reference level of +9 db above "typical" for 200 kc p-p deviation.

II. B. 1. Continuous Random Noise - Video

This measurement determines the weighted video signal-to-noise ratio, defined as the ratio of the peak-to-peak amplitude of the picture portion of the video signal (reference black to reference white) to the rms amplitude of the noise between 10 kc and 3.2 mc with the video removed. The signal level is adjusted using a half-line bar as a reference video signal. With the video signal removed, the rms level of the noise signal is measured after having been passed through a low-pass filter (CCIR Recommendation 267, Annex II) with and without a weighting network (CCIR Recommendation 267, Annex III).

The reported results of these measurements are presented in Table 2. In loop measurements the weighted signal-to-noise ratio at COMAND varied from 50 to 60 db, at COMBOD from 47 to 55 db, and at COMCON from 29 to 40 db. No loop measurements were performed from COMTEL because the station lacks a transmitting capability but received weighted signal-to-noise ratios varied from 19 to 42 db. The system objective for a maximum range of 5,000 nautical miles (9,266 km) was a weighted signal-to-noise ratio of 43 db. Several of the reported measurements were made at ranges greater than this maximum.

The expected unweighted video signal-to-noise ratio can be calculated using the formula given in the R1-0000 Project Relay System Requirements (page 47). These predictions can be inaccurate for a number of reasons: noise transmitted by the illuminating station, low transmitter power, uncertainties in deviations, improper illumination of the spacecraft, uncertainties in the spacecraft receiver noise figure, low spacecraft transmitter power, uncertainties in spacecraft antenna gain, and uncertainties in the ground receiving system noise figure and antenna gain.

In addition, if the noise spectrum is not triangular, the actual noise attenuation due to the weighting network will differ from the theoretical weighting factor, causing a further difference between expected and measured performance. Measured and expected results for several passes are presented in Table 3. Note that the difference between weighted and unweighted noise measured at COMBOD on Rev 200 is only 5 db, indicating that the spectrum is not triangular. The expected performance was calculated using the best data available concerning ground station parameters. The results indicate that system parameters should be more accurately established.

Table 2

Continuous Random Noise Measurements

Receiving Station	Rev	Transmitting Station	Received Power	Measured S/N	Type of Wtg.[1]	Pre-emphasis[2]	Type of Demod-ulator[3]
COMAND	162	COMCON	-85 $\pm$ 2 dbm	40-43 db	525 line	none	FMFB
		COMAND	-85 $\pm$ 3 dbm	50-60 db	525 line	none	FMFB
	163	COMCON	-84 $\pm$ 1 dbm	42 db	525 line	none	Discriminator
		COMCON	-83 $\pm$ 1 dbm	43 db	525 line	none	Discriminator
		COMCON	-81 $\pm$ 1 dbm	45 db	525 line	none	Discriminator
	175	COMAND	-87 $\pm$ 1 dbm	50.5-51.5db	525 line	none	FMFB
	200	COMBOD	-82 $\pm$ 1 dbm	54-55 db	525 line	Note 4	FMFB
COMBOD	200	COMBOD		42 db	none		
		COMBOD		47 db	405 line		
	330	COMBOD	-83 dbm	46 db	none		
		COMBOD	-83 dbm	55 db	405 line		
	355	COMBOD	-84 dbm	50 db	405 line		
COMCON	161	COMCON		35 db	405 line	none	
	162	COMCON		36 db	405 line	none	
	163	COMCON		37 db	405 line	none	
	170	COMCON		39 db	405 line	none	
	276	COMCON		35 db	405 line	none	
	292	COMCON		29-33 db	405 line	none	
	294	COMCON		35-40 db	405 line	none	
	370	COMCON		31-32 db	405 line	none	

Table 2 (cont'd)

Continuous Random Noise Measurements

Receiving Station	Rev	Transmitting Station	Received Power	Measured S/N	Type of Wtg. [1]	Pre-emphasis [2]	Type of Demodulator [3]
	565	COMCON		36-39 db	405 line	none	
COMHIL	192	COMCON	-95 dbm	38 db	405 line	none	
	200	COMBOD	-86 to 87 dbm	28 db	none		
COMTEL	245	COMBOD	-101 dbm	35.5 db	405 line	none	
		COMBOD		42 db	405 line	none	
	316	COMCON		35.5 db	405 line	none	
	323	COMAND		26-30 db	405 line		
	330	COMBOD		32 db			
	331	COMAND		32 db	405 line		
	338	COMCON	-99 dbm	31.5 db			
	370	COMCON	-106 dbm	19 db	405 line		
		COMCON	-102.5 dbm	23 db	405 line		
		COMCON	-99.5 dbm	28 db	405 line		
	463	COMHIL	-101 dbm	27.0 db			

Notes

1. Refers to CCIR Recommendation 267, Annex III.
2. Refers to CCIR Recommendation 277, 525 line pre-emphasis.
3. FMFB refers to the BTL FM Feedback Demodulator.
4. No pre-emphasis network reported, but de-emphasis network inserted.

Table 3

Measured and Predicted Video Signal-to-Noise Ratios

[1] Receiving Station	Rev	Measured S/N		Predicted Weighted S/N	
		Weighted	Un-weighted	Using Predicted RCVR Powers (from R1-0000)	Using Measured RCVR Powers
COMCON	192	37 db		43 db	39 db
COMCON	293	37 db		38 db	37 db
		35 db		40 db	37 db
COMCON	294	35 db		43 db	37 db
		40 db		45 db	40 db
COMBOD	200	47 db	42 db	59 db/47 db[2]	59 db/47 db[2]
COMAND[3]	200	54 db[4]		59 db	61 db
COMHIL[5]	200		28 db	/42 db[6]	/42 db[6]

Notes

1. Tests are looped unless noted.
2. 59 db weighted assuming triangular noise, 47 db unweighted - the unweighted value is given for a better comparison with the measured value.
3. COMBOD transmitting.
4. A de-emphasis network was used for this measurement although no pre-emphasis was reported.
5. COMBOD transmitting.
6. 42 db unweighted, no weighted value was computed.

II. B. 2. Continuous Random Noise-Audio

This measurement is designed to measure the ratio of rms signal power to rms noise power for the aural signal. The transmitted test tone should be at a level of +9 dbm 0 and produce a 200 kc peak-to-peak deviation of the subcarrier. The test is performed with an accompanying video signal.

The only measurements reported have been performed at COMCON and COMHIL. The COMCON results indicate an unweighted audio signal-to-noise ratio of 12 to 29 db. No pre-emphasis was used in the tests. The COMHIL report indicates an unweighted signal-to-noise ratio of 35 db on Rev 200. The peak-to-peak deviation for this measurement was 100 kc rather than 200 kc. The system objective is 50 db unweighted without pre-emphasis. Qualitative reports from stations participating in video demonstrations have indicated that the audio performance is satisfactory.

II. B. 7. Fluctuation Noise

This measurement determines the shape of the baseband noise sepctrum. Measurements of noise power can be made in narrow channels spaced throughout the baseband. An alternative technique utilizes a spectrum analyzer. The noise is expected to be triangular; that is, noise power proportional to frequency squared.

Results have been reported from COMAND and COMCON. COMAND results for Rev 175 are presented in Figure 1. The spectrum appears to be triangular above 500 kc and flat from 50 to 100 kc. COMCON results for Rev 565 are shown in Figures 2 and 3. The spectrum for the higher signal strength (-97 dbm) appears to fill in slightly at low frequencies, indicating that at higher signal strengths and at low frequencies receiver noise is not the only significant contributor to the system noise. Measurements were made both with a spectrum analyzer and with fixed bandpass filters. Both measurement techniques indicate a departure from a triangular characteristic at low frequencies.

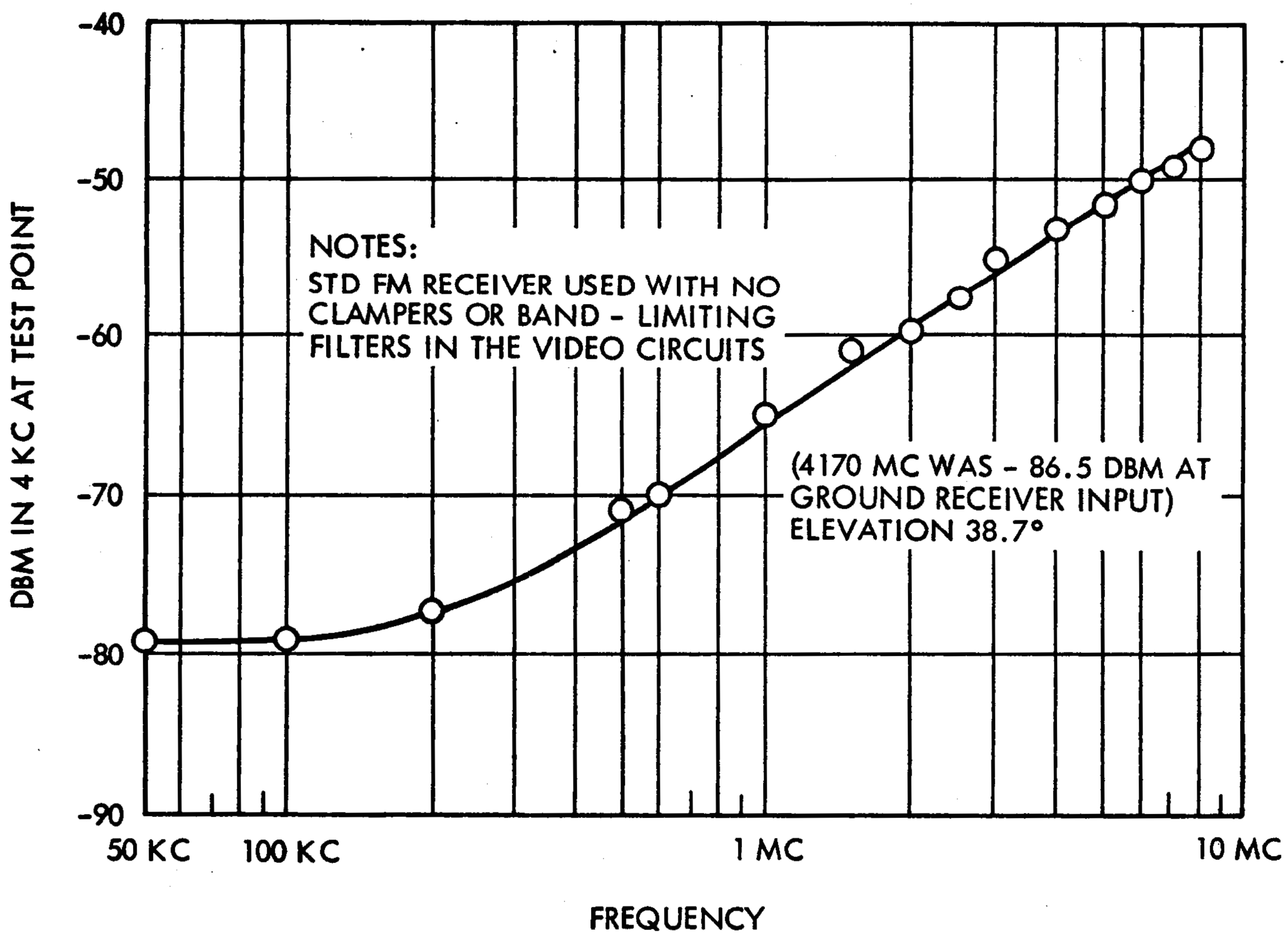


Figure 1. Baseband Noise Spectrum, Rev 175

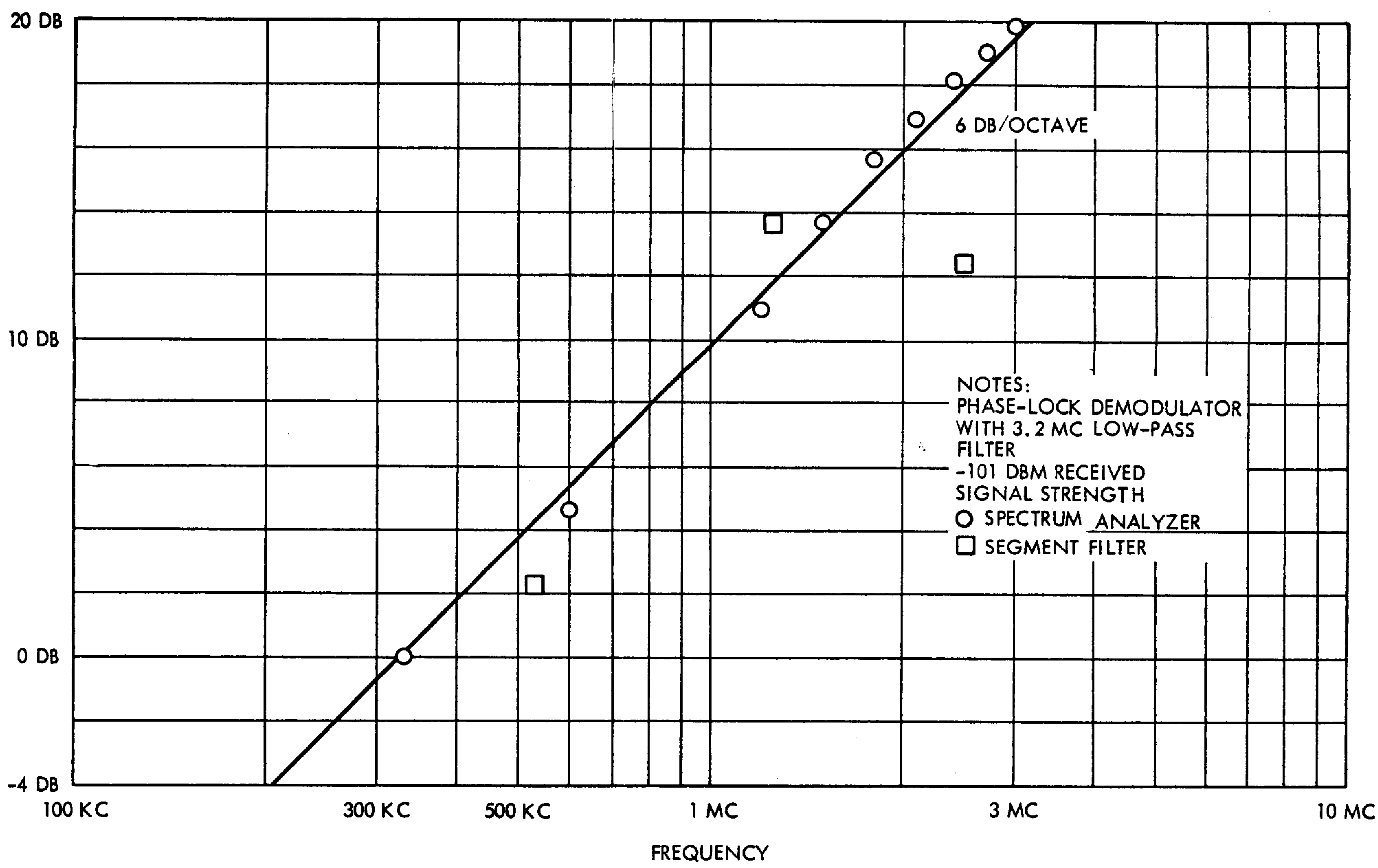


Figure 2. Baseband Noise Spectrum, Rev 565

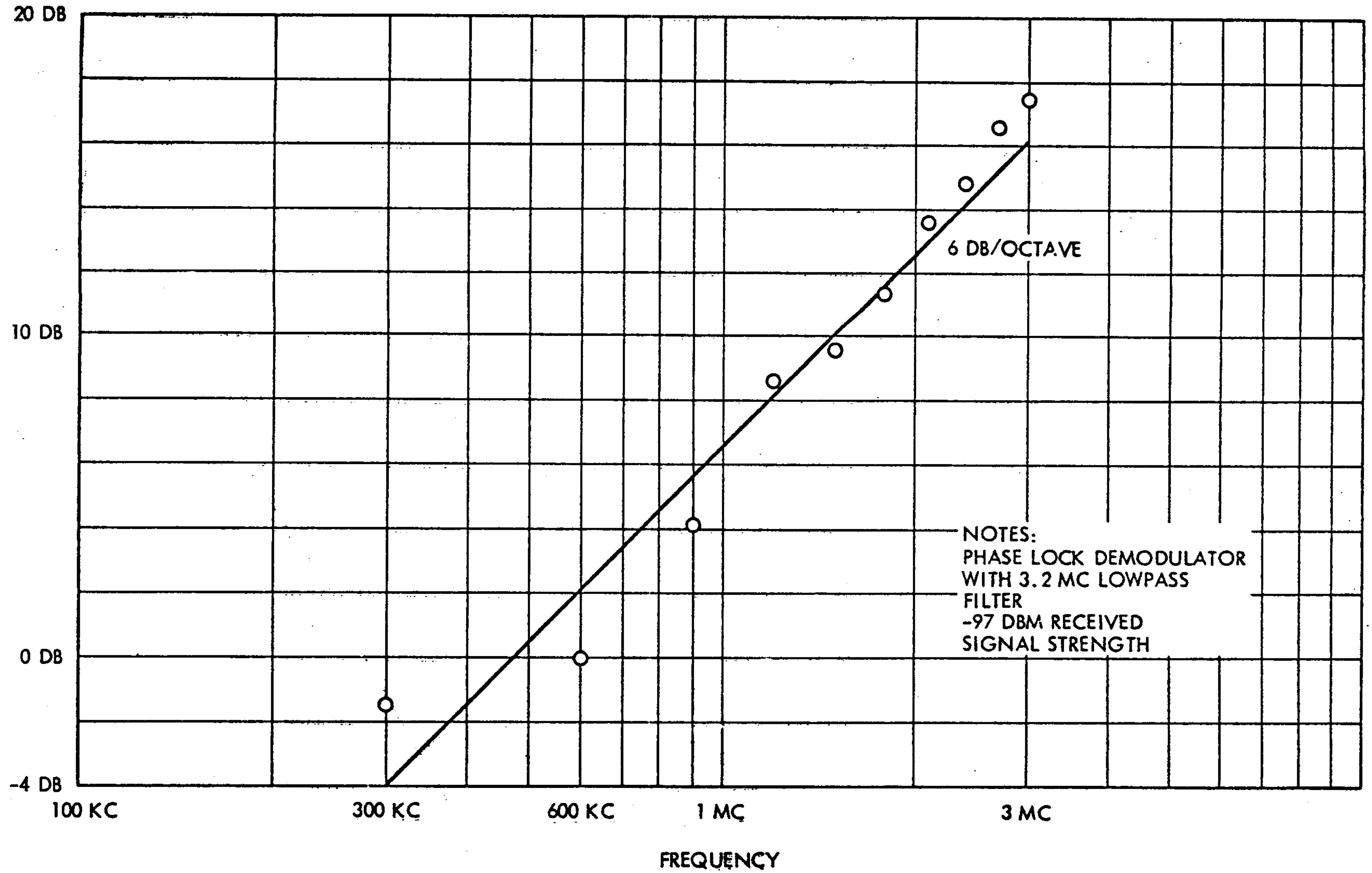


Figure 3. Baseband Noise Spectrum, Rev 565

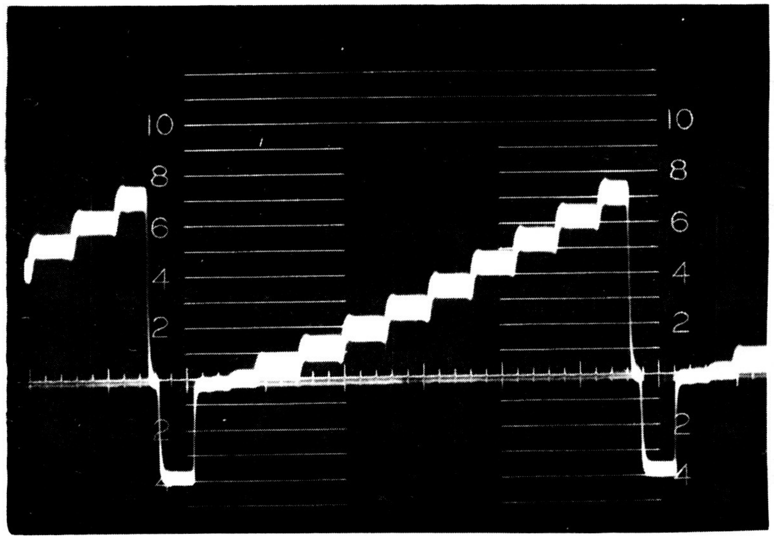
II. C. 1. Line Time Non-linearity

This measurement determines the gray scale response and the differential gain and differential phase response of the system. For gray scale response a stairstep signal is transmitted. Non-uniform steps on the received signal indicate poor gray scale response. The test signal for differential phase and gain measurements is made up of a low-level high-frequency signal added to a line-rate stairstep, ramp, or sine wave signal. The high frequency signal is separated from the received low frequency and examined for variations in gain and phase.

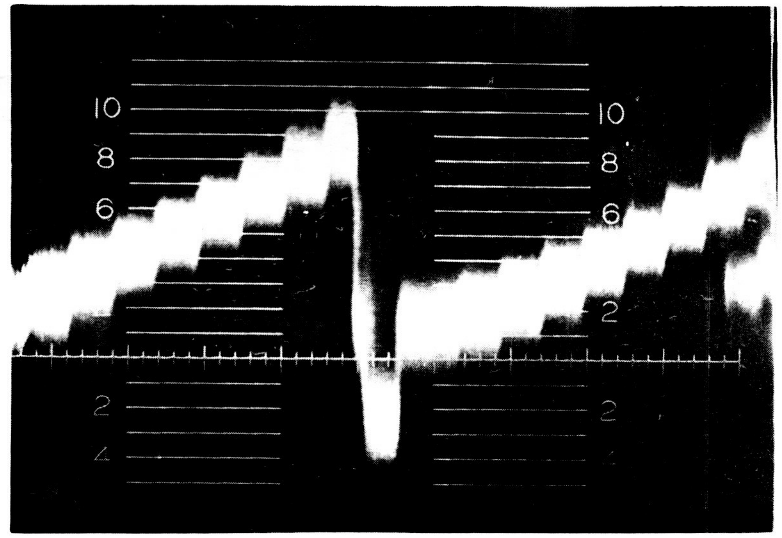
Stairstep response has been reported by COMCON and COMHIL. Photographs of these signals are presented in Figures and . The photographs do not indicate any signficant distortion.

Differential gain measurements have been performed at COMCON using a 1 mc low-level signal superimposed on a line-rate ramp signal. Results for Rev 565 are presented in Figure . The m/M ratio for this measurement is approximately 0.9. The system objective is m/M greater than 0.8.

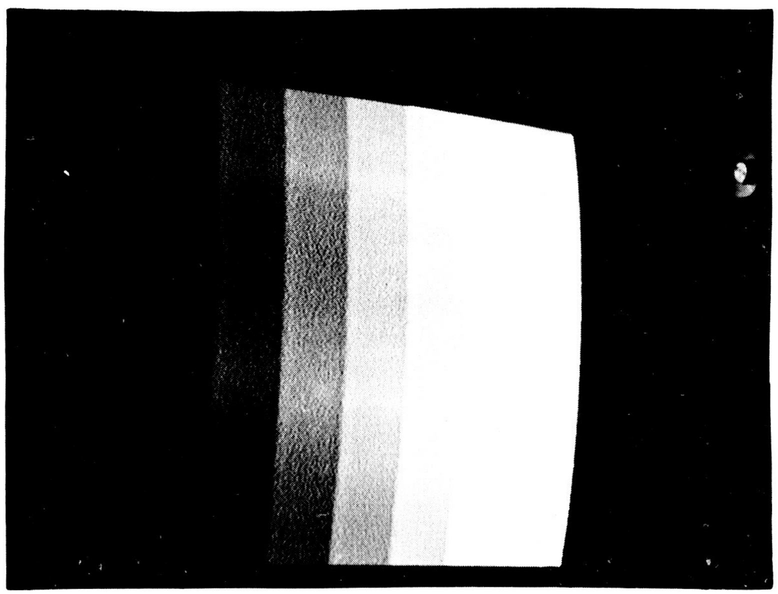
No measurements of differential phase were reported.



Transmitted Signal from COMCON



Received Signal at COMCON



Monitor Presentation of
Received Signal at COMMOJ

Figure 4. **Stairstep Response**, Rev 565

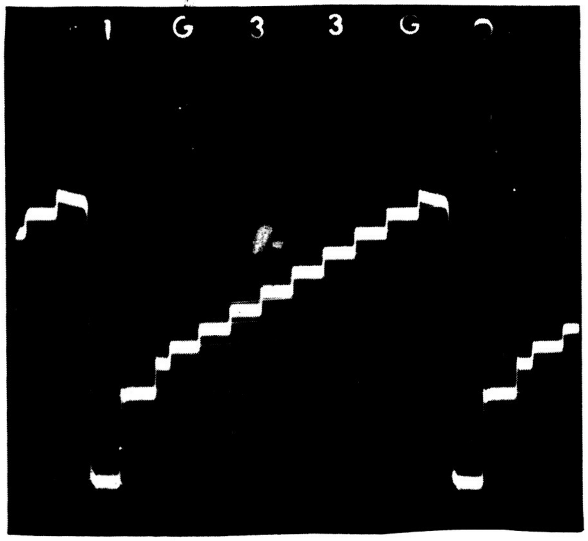
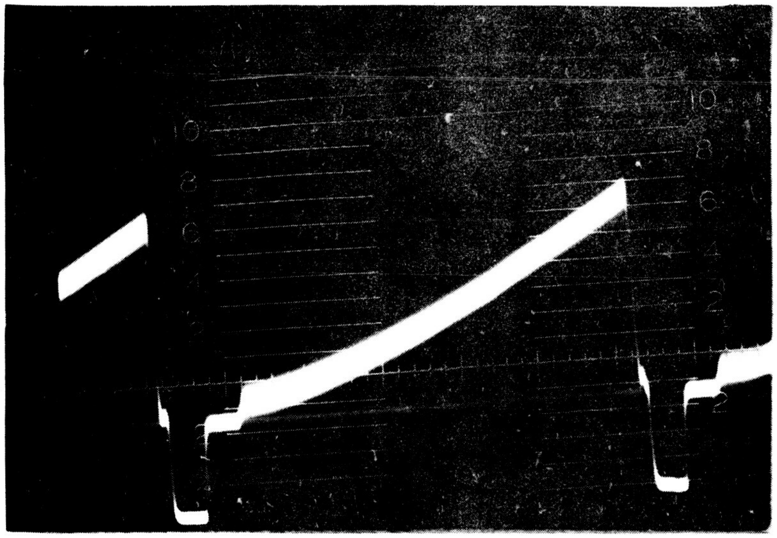


Figure 5. Stairstep Response, COMHIL, Rev 206

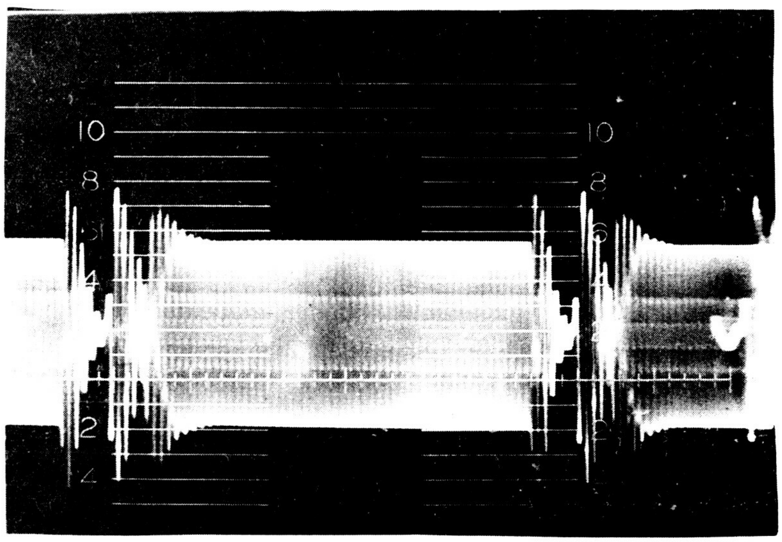
NOTES:

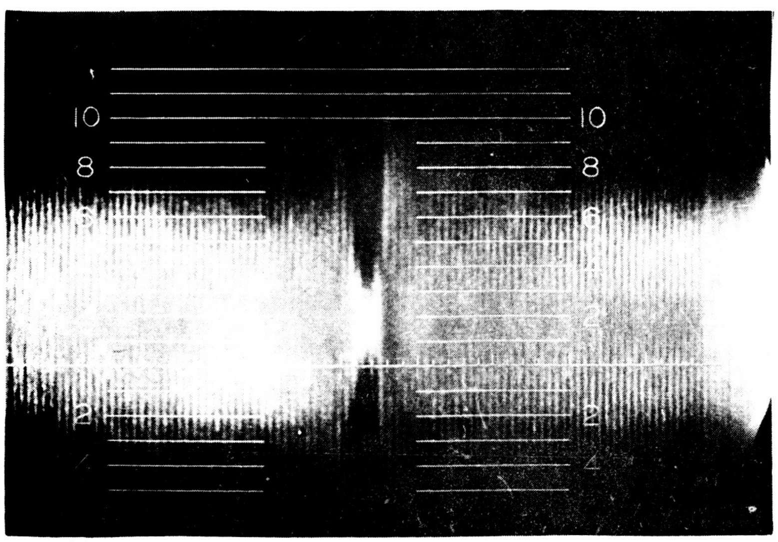
1. Signal transmitted using 525-line pre-emphasis and de-emphasis.
2. Baseband bandwidth was 3.2 mc.
3. The D.T.V.B. demodulator was used for this measurement.



transmitted signal

calibration
received signal





received signal

Figure 6. Differential Gain Measurement, COMCON, Rev 565

II. C. 3. Audio Distortion

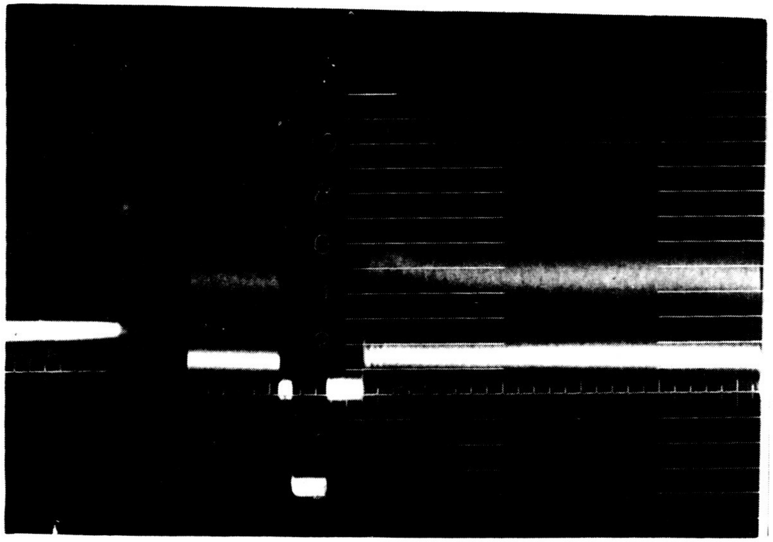
This measurement determines the total distortion percentage for single frequency tones in the audio baseband. At the receiving station a notch filter removes the transmitted tone, and the level of the remaining signal is measured. This method of measurement also includes the noise in the audio channel; therefore, the measurement results will be valid only at high audio signal-to-noise ratios.

COMCON was the only station to report results for this test. During Rev 170 total distortion plus noise measured 5%; the audio signal-to-noise ratio was 29 db. For Rev 294 8% was reported with a 28 db signal-to-noise ratio. The frequency of the test tone was 400 cps. The system objective for this modulating frequency is 2.0% at a 50 db audio signal-to-noise ratio.

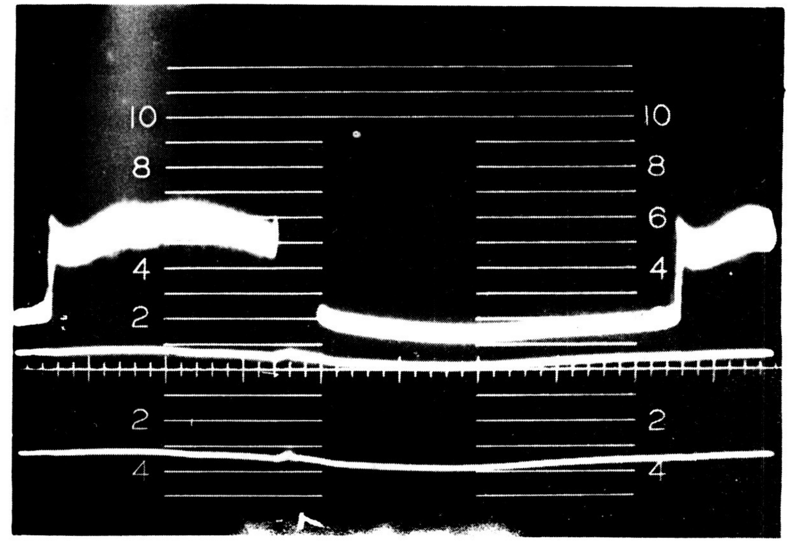
II. D. 1. Field Time Distortion

This measurement determines the system response to field time waveforms. The transmitted signal is a square wave at the field rate (50 or 60 cps), which has maximum and minimum levels corresponding to peak white and peak black picture levels respectively. The demodulated signal is compared to the performance characteristic presented in Recommendation 267, Annex 4 of the CCIR Recommendations. The test signal may originate in a test generator or be derived from a half-white, half-black test slide. The first method seems to produce a more accurate test signal. Poor low frequency response will cause distortion of this test signal.

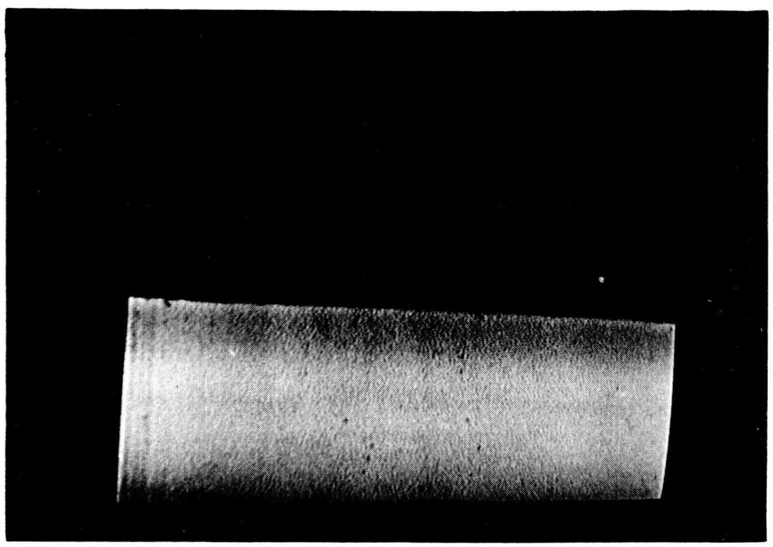
COMCON is the only station reporting results from this test. These results are shown in Figure 7 . Comparison of calibration pictures and pictures through the spacecraft indicate that any distortions due to spacecraft response are masked by the quality of the test signal or by ground equipment distortions. Qualitative observations have indicated no significant distortions of this type.



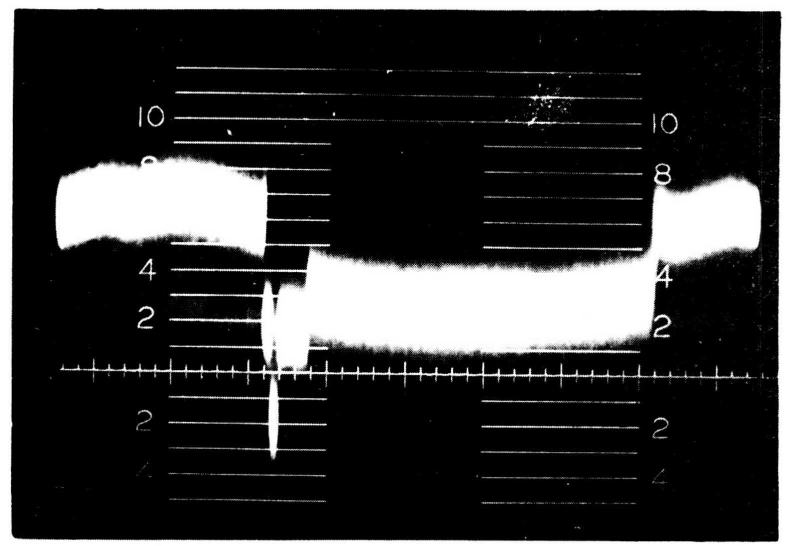
Transmitted Signal, COMCON, Rev 511



Calibrated Signal, COMCON, Rev 511



Monitor Presentation of Received Signal
COMMOJ Rev 565



Received Signal, COMCON Rev 511

Figure 7. Field Time Distortion

II. D. 2. Line Time Distortion

This measurement indicates the system response to line-rate waveforms. The test waveform consists of a half-line bar with sine-squared transitions with a 10 to 90% rise time of 0. 33 microseconds and a sine-squared pulse of 0. 33 or 0. 17 microsecond half-amplitude duration. Both the bar distortions and the pulse-to-bar ratio of the received signal are examined. The test signal is described and response limits indicated in CCIR Recommendation 267, Annex IV. Distortions in the bar portion of the waveform indicate poor phase and amplitude response from the line rate up to several hundred kilocycles.[1, 2] Ringing on the transitions indicates poor high frequency response. Distortions generally are caused by baseband equipment.

Measured results have been received from COMHIL and COMCON for several revolutions. Measurements made at COMHIL during Revs 176 and 206 are presented in Figure 8 . The measurements from Rev 176 were performed without pre-emphasis, while those of Rev 206 included pre-emphasis. The pre-modulation and post-detection bandwidth was 3. 2 Mc in both measurements. No tilt is indicated. Ringing appears on the front edge of the bar and following all abrupt transitions. Pre-emphasis does not appear to affect the response. The monitor presentations indicate that this amount of ringing does not impair the generally excellent picture quality. The bar-to-pulse ratio for Rev 176 was 1. 05. A bar/2 T pulse ratio of 1. 02 was reported on Rev 184. COMCON results for Rev 511 are presented in Figure 9 . A 7% overshoot is indicated on the front edge of the bar. The bar-to-pulse ratio is approximately 1. 1.

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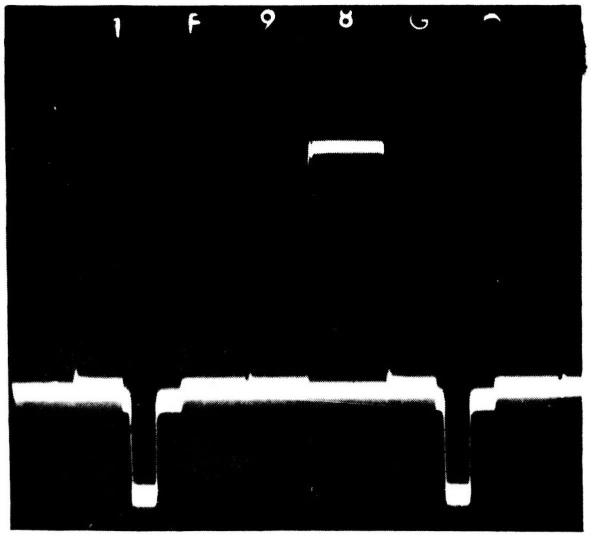
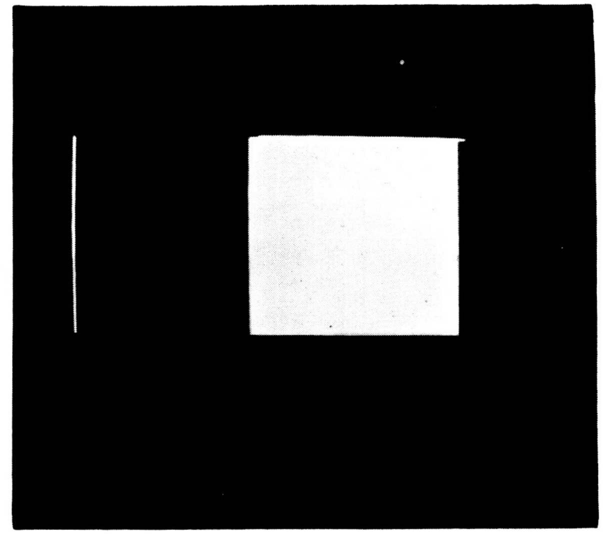
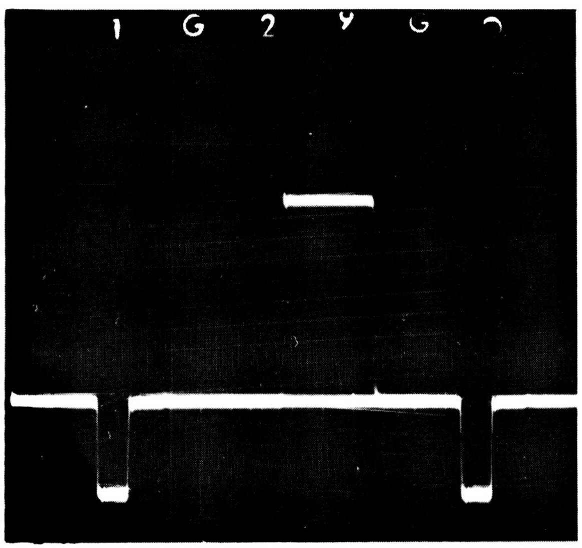
[1] N. W. Lewis, Waveform Responses of Television Links, Proc. I. E. E., Volume 101, Part III, No. 72, July 1954.

[2] R. Kennedy, Sine-Squared Pulses in Television System Analysis, RCA Review, June 1960.



Received Pulse and Bar Waveform
COMHIL, Rev 176
525-line standards
no pre-emphasis
D. T. V. B. demodulator
pre-modulation and
post-detection bandwidth, 3.2 mc





Received White Window Waveform
COMHIL, Rev 206
525-line standards
525-line pre-emphasis
D. T. V. B. demodulator
pre-modulation and
post-detection bandwidth, 3.2 mc

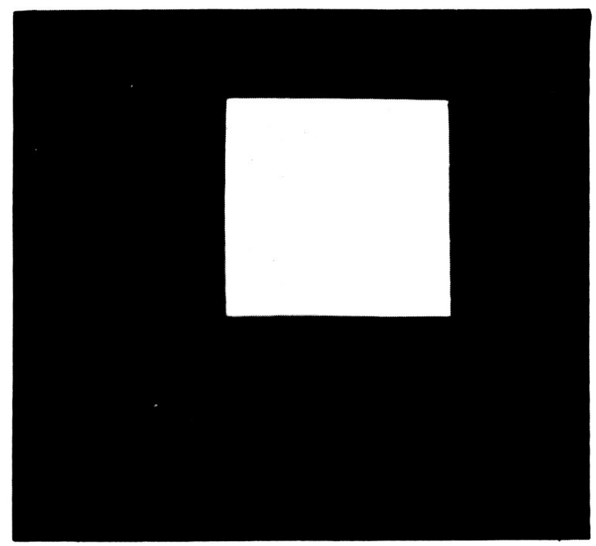
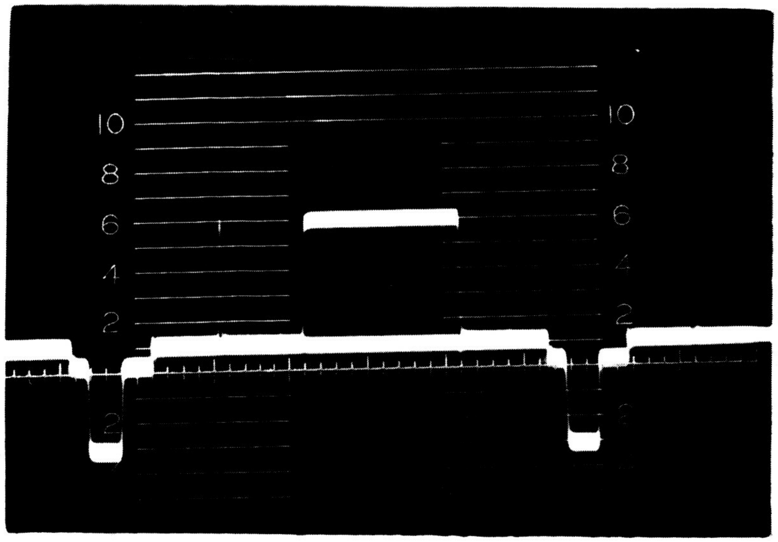
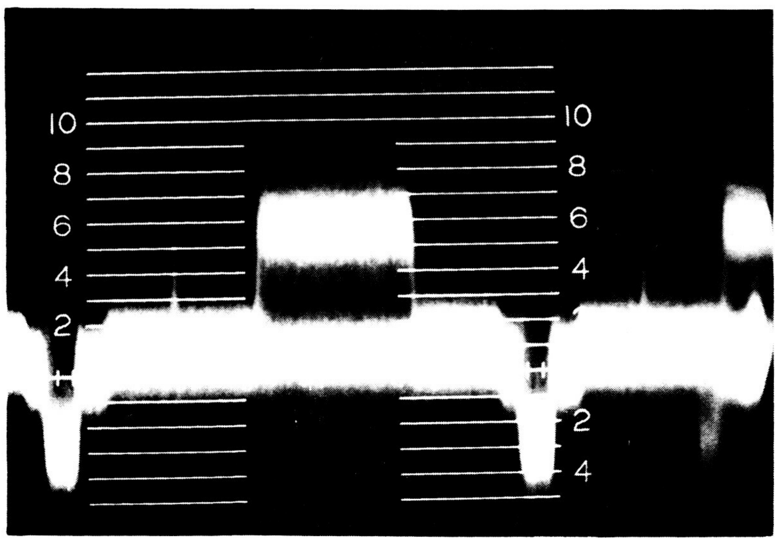


Figure 8. Line Time Distortion



Transmitted Signal



Received Signal

Figure 9. Line Time Distortion, COMCON, Rev **511**

II. D. 3. Short Time Distortion

This measurement determines the response of the system to waveforms of the order of a single scanning spot output. The test signal is a sine-squared pulse transmitted with a half-line bar. The pulse amplitude should correspond to a peak-white excursion. The test signal and performance criteria are described in CCIR Recommendation 267, Annex IV. The pulse half-amplitude duration is 0. 33 microseconds (2 T-pulse) or 0. 17 microseconds (T-pulse). Pulse amplitude, duration, ringing and overshoot are examined to determine system performance. The test indicates response from 0. 5 to 3 Mc.

No complete results have been reported; however, partial results are available from COMCON and COMHIL. Figure 10 shows a calibration T-pulse signal and a T-pulse signal received through the spacecraft on Rev 511 at COMCON. A comparison of the calibration and received waveforms indicates a spacecraft delay characteristic which increases with frequency.[3] First-lobe trailing is 10%. This is approximately equal to the system objective for this type of distortion. Figure 11 shows calibration and received 2 T pulses from COMCON during Rev 511. Again a delay increasing with frequency is indicated for the spacecraft. The first-lobe trailing is approximately 14%, again approximately equal to the system objective for this distortion. No information on pulse broadening or amplitude reduction is available from COMCON. A first-lobe trailing of 13% and second-lobe trailing of 6% can be observed on the line time presentation of the 2 T pulse and bar waveform in Figure 12 . The photo was taken at COMHIL during Rev 184. These observations are again within the system objective.

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[3] Kennedy, ibid., Page 258

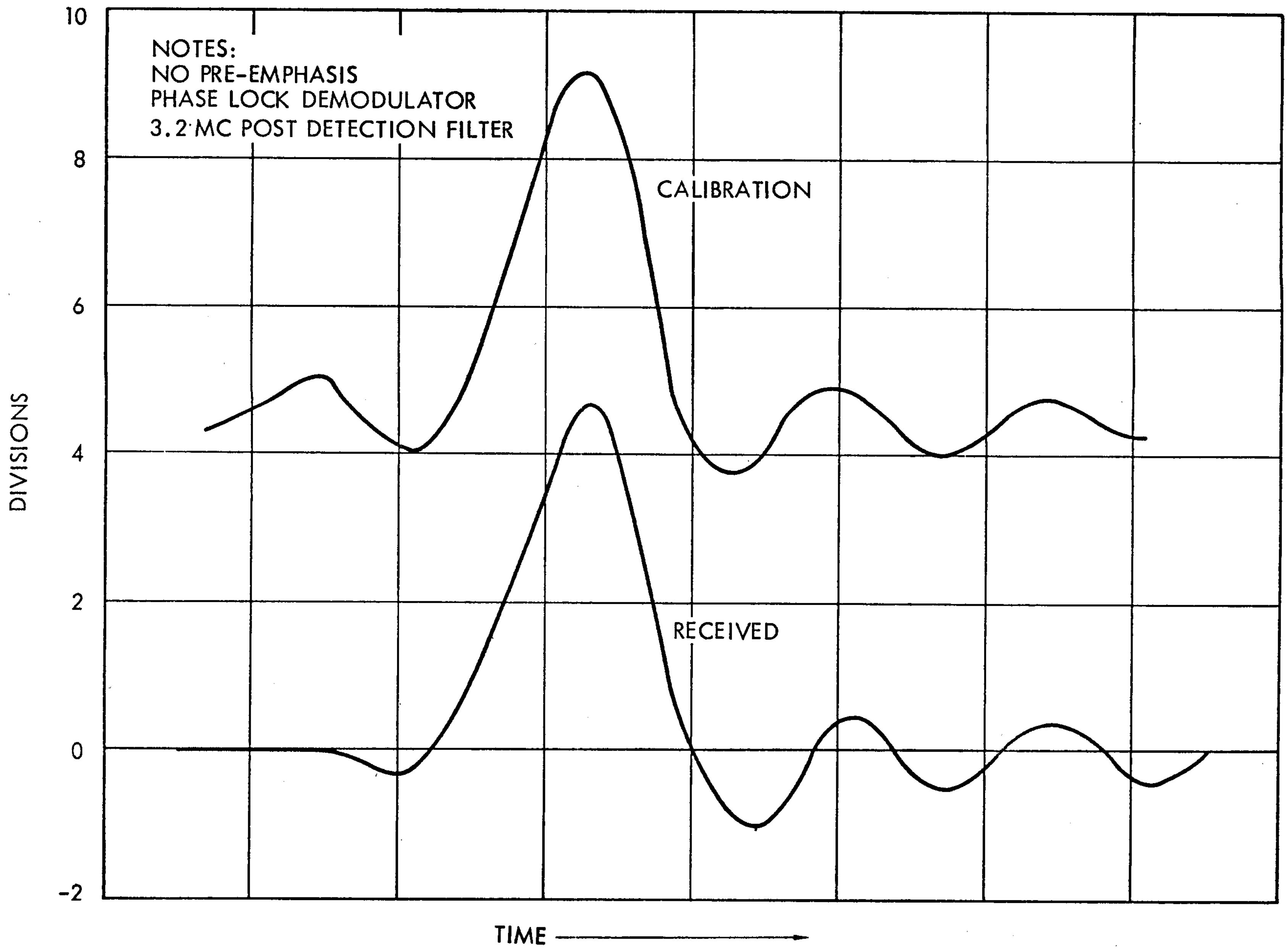


Figure 10. T-Pulse Response, COMCON, Rev 511

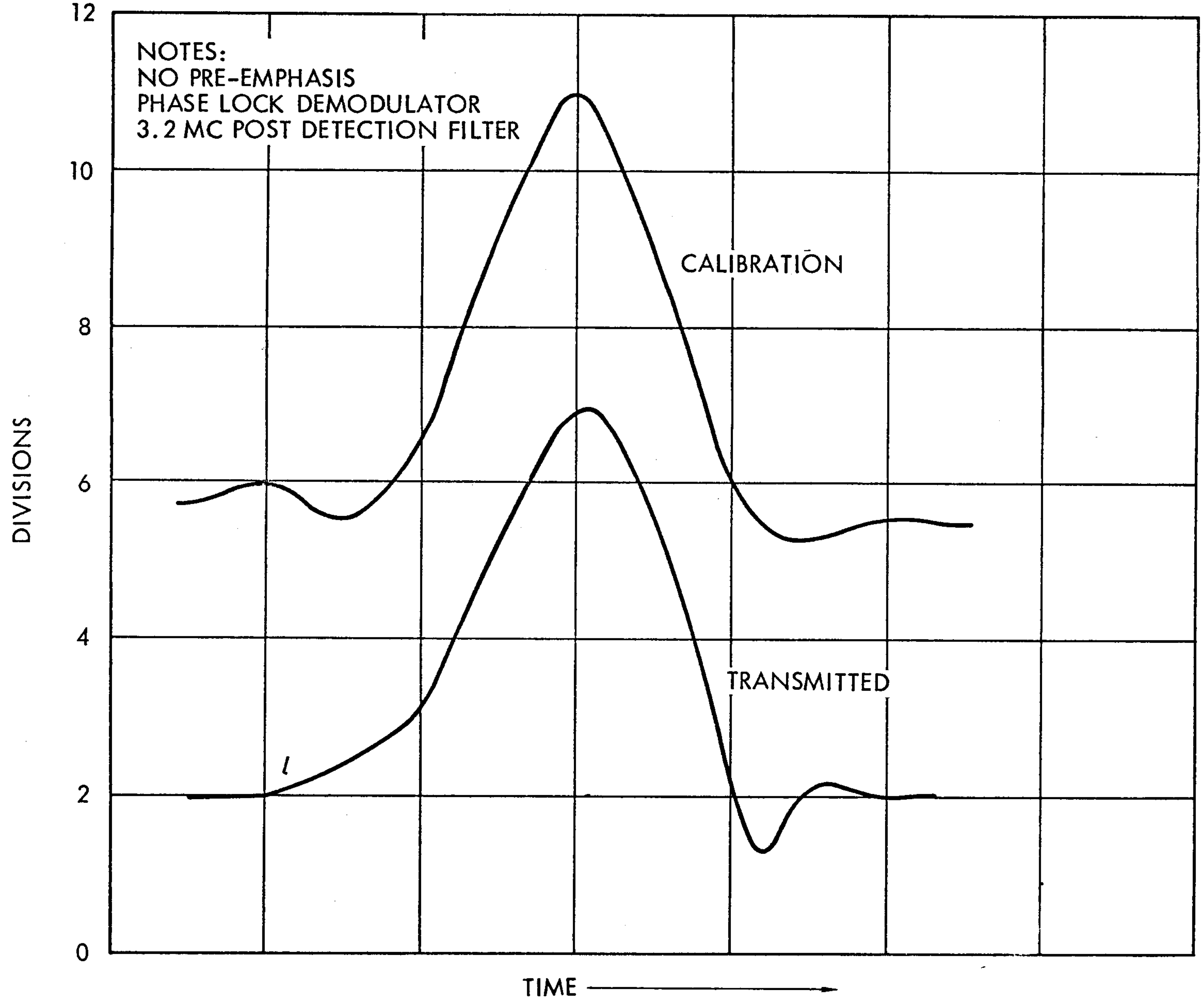
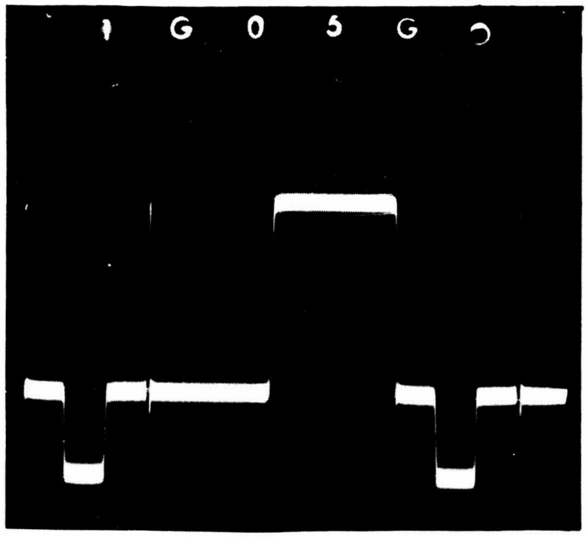


Figure 11. 2T-Pulse Response, COMCON, Rev 51



2T Pulse and Bar Waveform

Figure 12. Short Time Distortion, COMHIL, Rev 184

II. E. 1. Bandpass Characteristic

This measurement determines the baseband amplitude frequency response characteristic. The test may be performed using single tones or a swept signal. The system objective calls for a bandpass of 3 mc.

COMAND has reported bandpass measurements for Rev 175. These results are shown in Figure 13 . The characteristic shows a 0.2 db dip from 0.8 to 2.0 mc and a comparable hump between 2.5 and 4.0 mc. The response is 1 db down at 6 mc and 3 db down above 7 mc. The cutoff characteristic (above 5 mc) follows closely the response measured through the IF loop. The hump in the response appears to be due to the spacecraft. The measured characteristic should contribute no loss of video picture quality.

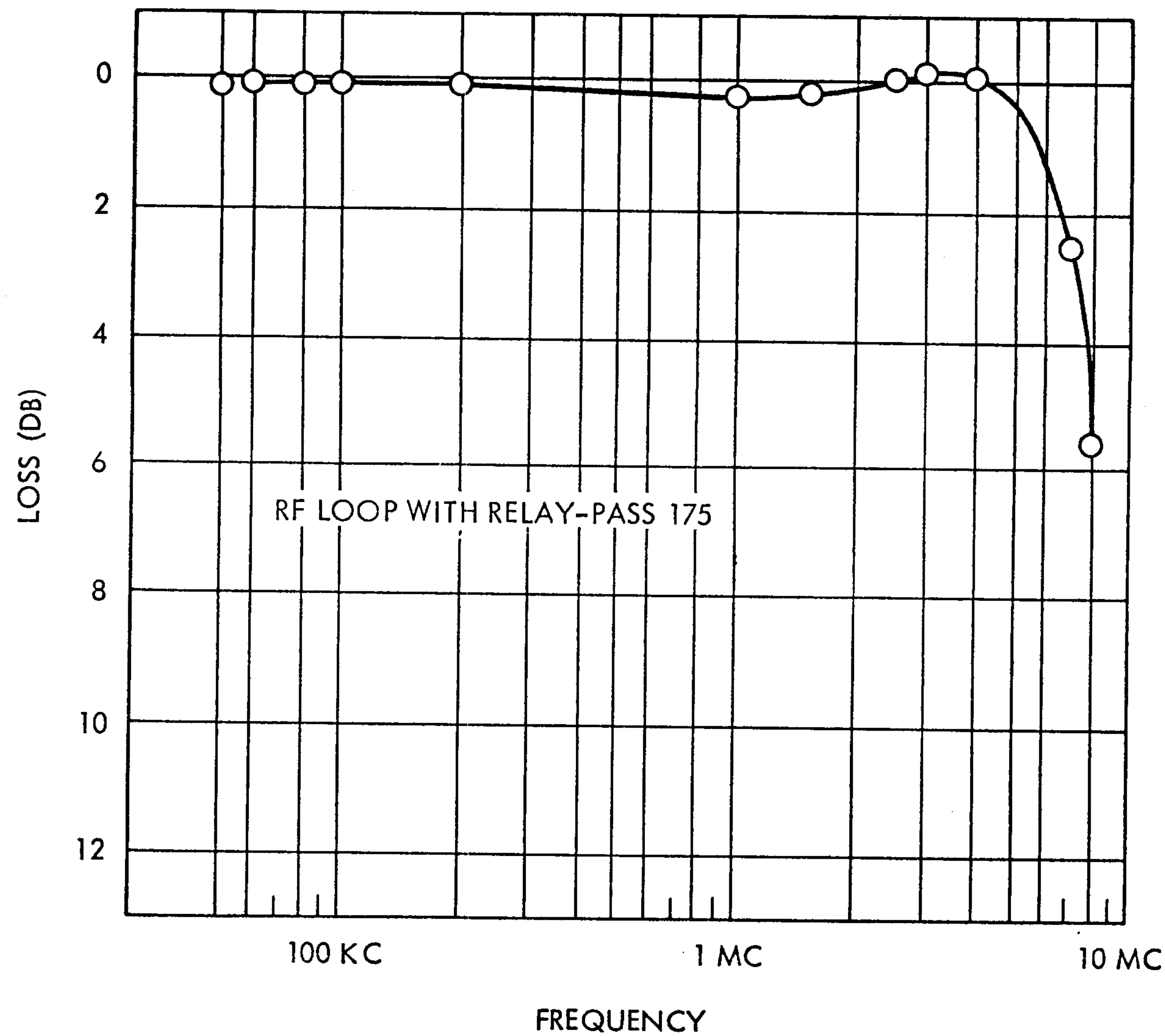


Figure 13. Bandpass Characteristics, Wideband

II. E. 4. Differential Time Delay - IF

The purpose of this test is to measure the differential time delay or envelope delay over the carrier frequency band. The envelope delay is the derivative of phase with respect to frequency, so that variations of the linearity of the phase characteristic with frequency show up as nonconstant delay. Therefore, the delay characteristic is a measure of the phase linearity of the link which for an FM or PM system causes intermodulation noise. Although baseband nonlinearities, multipath echoes and feeder reflections can also be significant, the delay characteristic is generally regarded as the major system nonlinearity for FM and PM systems.

To measure differential time delay a small amplitude, high frequency sinewave signal swept across the IF band by a large amplitude, low frequency sweep signal. The differential time delay is proportional to the differential phase modulation suffered by the high frequency sinewave as the low frequency signal sweeps over the IF band. Such a measurement is identical in concept to a differential phase measurement for a TV system, except that the amplitude range of the sweep signal and the frequency of the high-frequency signal are generally different. The differential phase is equal to the differential time delay multiplied by the frequency of the high frequency signal in rad/sec.

Differential delay measurement results are generally expressed in terms of linear, parabolic, and ripple components, because these constituents are generally sufficient to describe the delay variations of a communications link.

The differential time delay results reported to date are given in Table 4. Also presented are the values of telephone channel intermodulation noise calculated for these components of delay distortion. In addition, the RCA test results for envelope delay of the spacecraft before launch are given.

The results agree fairly well, at least in regard to order of magnitude of envelope delay for the system. Correlation with noise loading results can be examined when more data is available on delay measurements and on noise loading.

Table 4

Differential Time Delay Results

COMAND (Rev 200)

	Delay over 24 mc band (downlink)	N_{pw}(300 Channels with pre-emphasis)
Peak-to-Peak Linear Delay	45 ns	1000 pw
Peak-to-Peak Parabolic Delay	30 ns	60 pw
Peak-to-Peak Ripple Delay	10 ns (5 to 6 mc period)	800 pw

COMBOD (Rev 270)

Standard Demodulator

Total Delay = -36 ns for 20 mc p-p deviation

Total Delay = -20 ns for 10 mc p-p deviation

Feedback Demodulator

Total Delay = -36 ns for 20 mc p-p deviation

Total Delay = -28 ns for 10 mc p-p deviation

RCA Test Results on Spacecraft

Temperature: 25° C		Bandwidth: 23 mc (downlink)
Peak-to-Peak Linear Delay	2.3 ns	
Peak-to-Peak Parabolic Delay	27.8 ns	
Temperature: 0° C		Bandwidth: 23 mc (downlink)
Peak-to-Peak Linear Delay	36.7 ns	
Peak-to-Peak Parabolic Delay	8.05 ns	

II. E. 5. Audio Amplitude Frequency Characteristic

This test determines the amplitude frequency response of the audio channel. Single frequency tones are used as test signals. The system objective calls for an audio 3 db bandwidth extending from 50 cps to 8 kc.

The reported results were measured at COMBOD during Rev 362. The measurement was performed in loop configuration. The reference level was chosen as 0 db for a 1 kc tone. At 8 kc the level was -4 db, and at 30 cps the measured level was -1.8 db. The low-frequency response appears adequate, while the high-frequency response is only slightly worse than the system objective.

II. F Received Carrier Power

This measurement determines the total carrier power received at the participating ground stations during wideband experiments. The carrier power is determined by measuring the ground receiver AGC signal, which is calibrated for received power. This measurement is useful for comparison with performance objectives (link power budgets), evaluation of tracking performance, and correlation with other experiments. Predictions of received carrier power can be inaccurate because of low spacecraft transmitted power (measured by the telemetry system), uncertainties in the spacecraft antenna gain, and uncertainties in the ground system losses and antenna gain.

Reported results are summarized in Table 5. Maximum and minimum values and typical variation over one pass are given. The expected 5,000 nautical mile performance as stated in the Project Relay I System Requirements R1-0000 is also presented.

Comparisons of measured and predicted received carrier power over the duration of a pass are shown in Figures 14 , 15 , 16 and 17 for COMAND, COMBOD, COMCON and COMHIL. No antenna gains were available from COMTEL. The calculated values were based on the spacecraft antenna gain pattern shown in Figure 18 , telemetered values of transmitted power, ground system antenna gains as indicated on each curve, and other losses as stated in R1-0000. The measured values were taken from operations reports for COMAND and COMBOD and experiment analysis reports for COMCON and COMHIL. Measured values agree fairly well with calculations except for those from COMCON.

A comparison of spacecraft received signal strength with expected results is presented in Figures 19 and 20 . Figure 19 shows the variation of signal strength received at the spacecraft during Rev 200 with COMAND and COMBOD transmitting in succession. Figure 20 presents the spacecraft received signal strenth during Rev 565 with COMCON transmitting. Measured values were obtained from spacecraft Class II telemetry data. The predictions were based on the spacecraft antenna patterns shown in Figure 18, a transmitted power of 10 kw, ground system antenna gains as given on each figure, and other losses as used in the R1-0000 link calculations. Results from both COMAND and COMBOD indicate higher spacecraft received power than predicted. This indicates that the telemetry calibration gives a value which is too high by at least 3 db. If this is the case, COMCON results are again lower than predicted. The results indicate a greater signal discrepancy on the spacecraft-to-ground link. This could be due to a tracking problem, since the antenna beam width at 4170 Mc is much narrower than at 1725 Mc.

Variations of received signal strength coinciding with the vehicle spin rate have been reported on many wideband passes. Peak-to-peak variations of received power of 2 to 4 db have been reported by COMHIL, 2 to 8 db by COMCON, 3 to 7 db by COMBOD and 3 db by COMTEL. The reported spin rates have varied from 166 rpm during Rev 175 (COMHIL) to 150 rpm during Rev 565 (COMCON). A typical spin pattern is presented in Figure 21 . The specific waveform is determined by the response of the AGC system, but a definite periodicity at 150 rpm is discernible. From the spacecraft antenna pattern one would expect a peak-to-peak spin modulation varying from 3 db at a look angle of 90° to 6 db at a look angle of 150°; this agrees closely with the reported values. A noticeable variation of noise level occurring at the spin rate has been reported when the signal levels are near threshold. This effect may be predicted from demodulator threshold performance.

Several discontinuities during experiment periods have been caused by tracking problems. Some problems have been encountered when the spacecraft orbit required tracking through the zenith, since COMAND, COMBOD, and COMNUT have an elevation limitation of 85°. Other problems have been due to excessive wind loads and equipment failure. In general, however, tracking performance has been excellent.

Table 5

Measured Wideband Received Carrier Power[1]

Receiving Station	Minimum Reported Value	Maximum Reported Value	Typical Variation over one Rev	Expected[2] Performance (5000 n. m.)
COMAND	-91 dbm	-81 dbm	3-4 db	-89.6 dbm
COMBOD	-93 dbm	-82 dbm	3 db	-89.6 dbm
COMCON	-103.5 dbm	-95 dbm	4-5 db	-96.1 dbm
COMHIL	-93 dbm	-85 dbm	4-5 db	-88.8 dbm
COMTEL	-107 dbm	-98 dbm	3-4 db	-95.9 dbm

Notes

1. Based on values from operations reports.
2. Taken from R1-0000 Project Relay I System Requirements and based upon a maximum range of 5,000 nautical miles (9,266 kilometers.) Some reported measurements were made at ranges greater than this nominal limit.

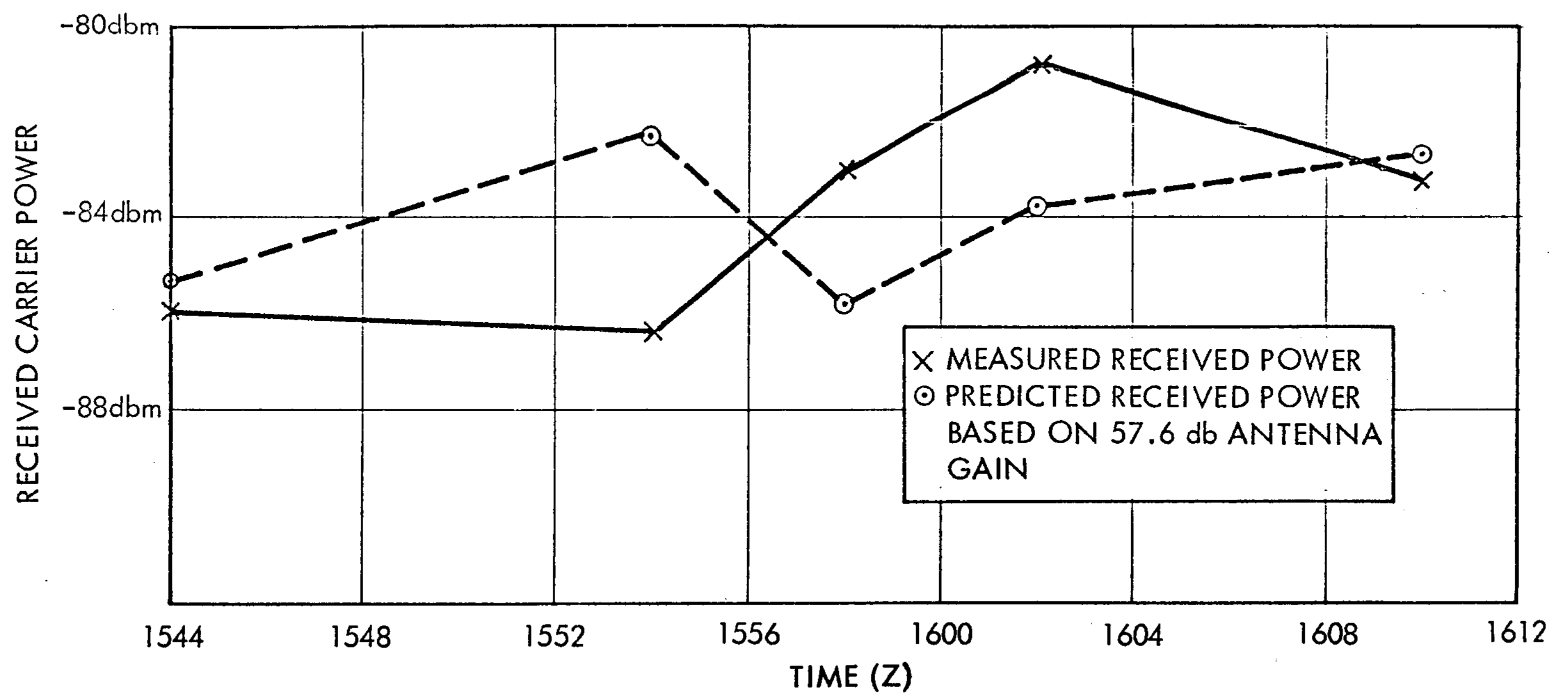


Figure 14. Received Carrier Power, COMAND, Rev 200, 8 January 1963

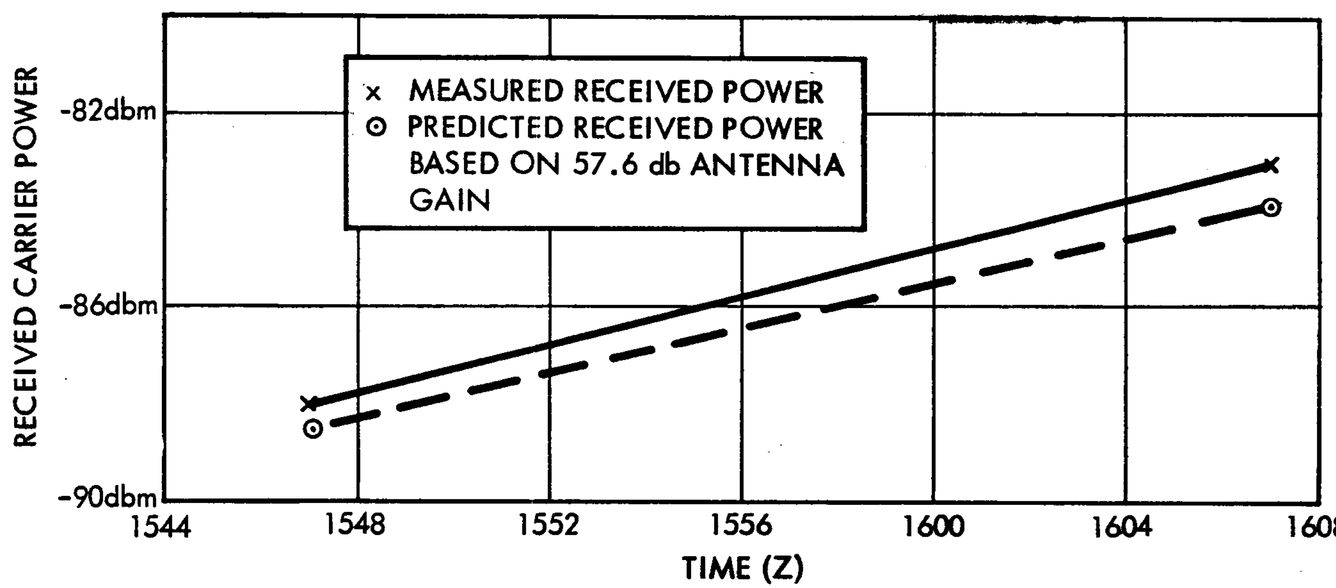


Figure 15. Received Carrier Power, COMBOD, Rev 200, 8 January 1963

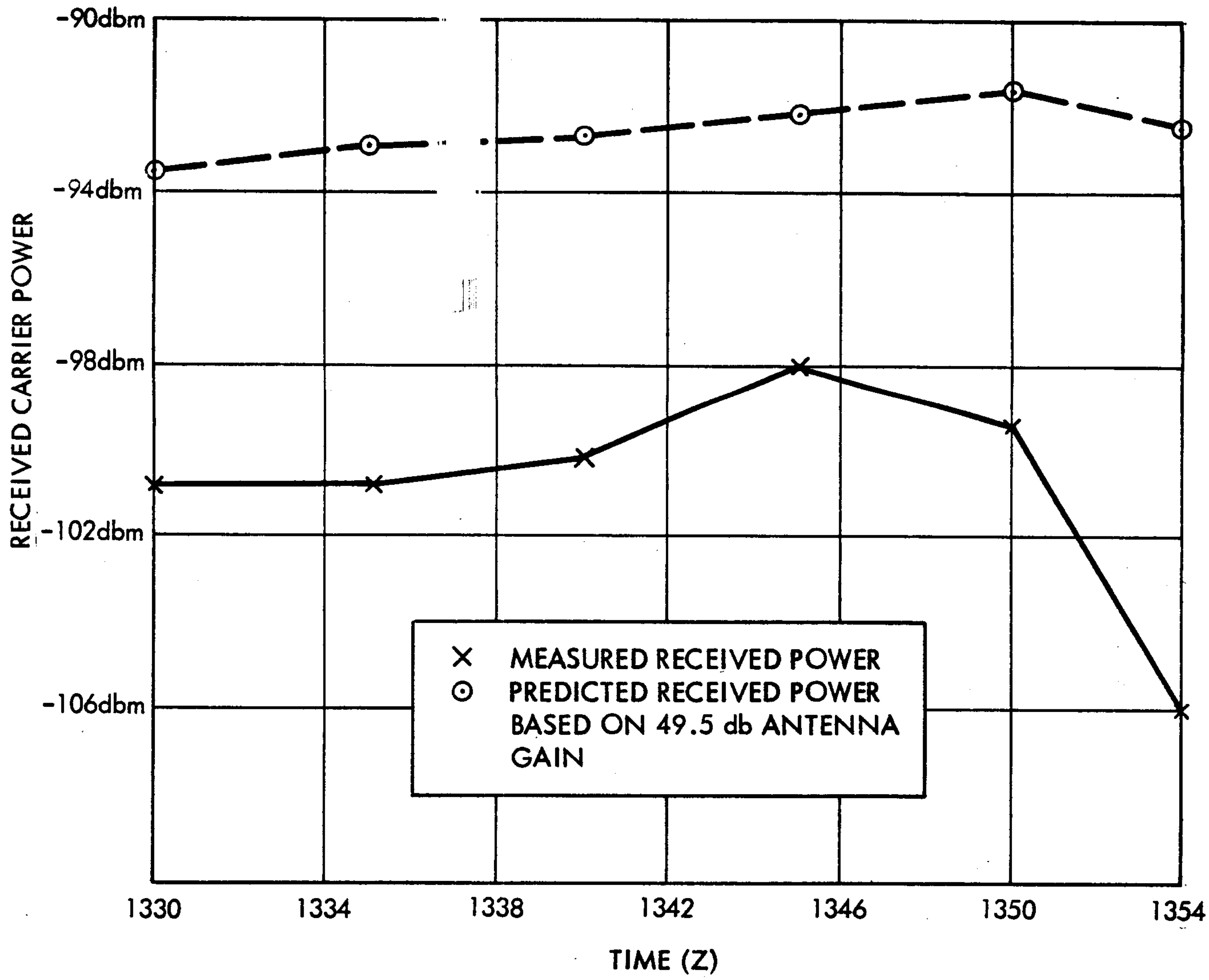


Figure 16. Received Carrier Power, COMCON, Rev 565, 24 February 1963

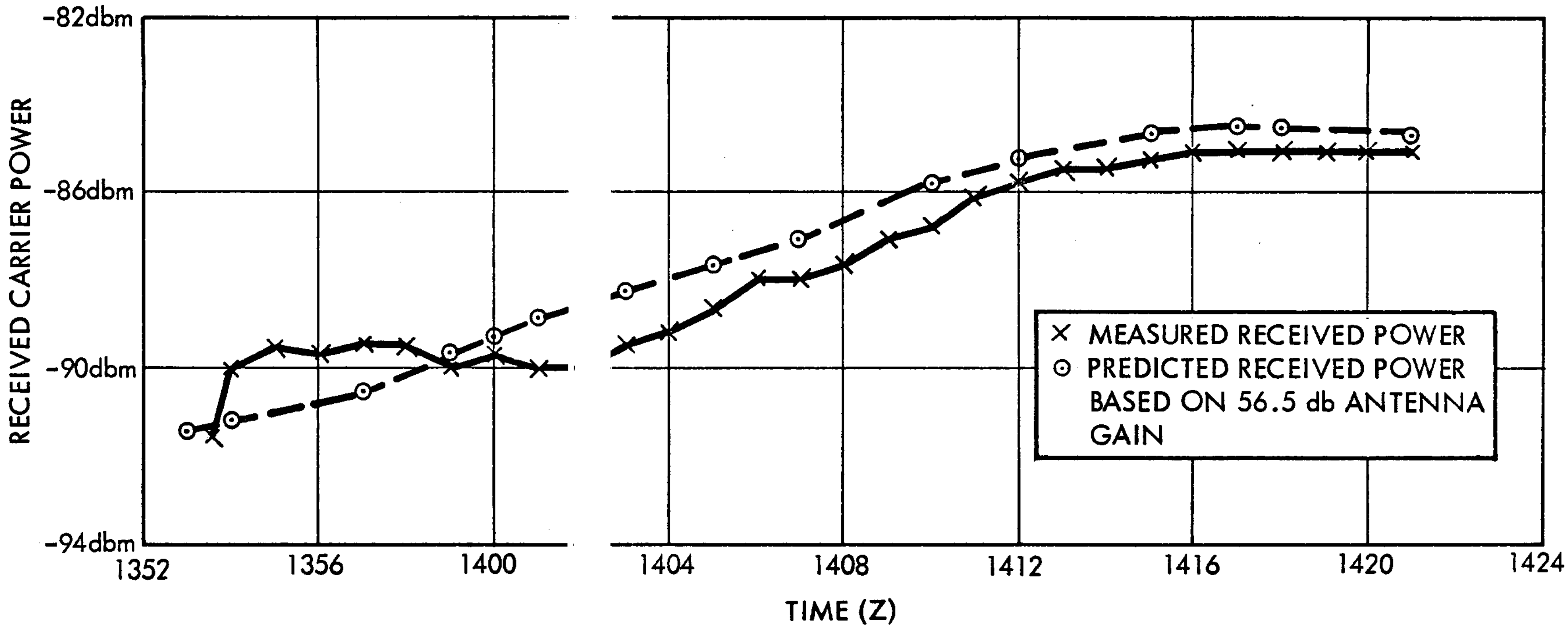


Figure 17. Received rrier Power, COMHIL, Rev 285, 19 January 1963

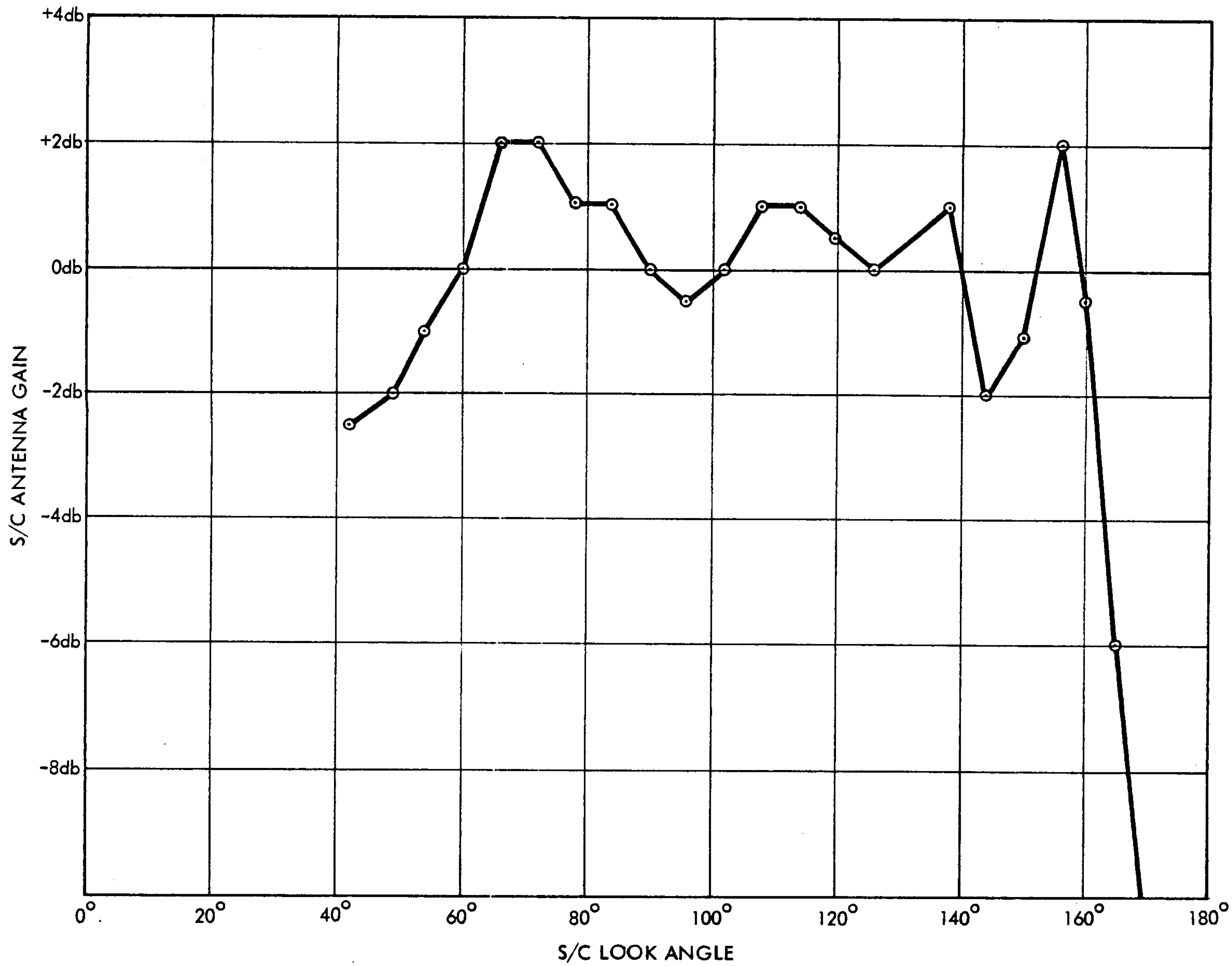


Figure 18. Spacecraft Antenna Gain as a Function of Look Angle (or Rad. Angle Measured from Tail)

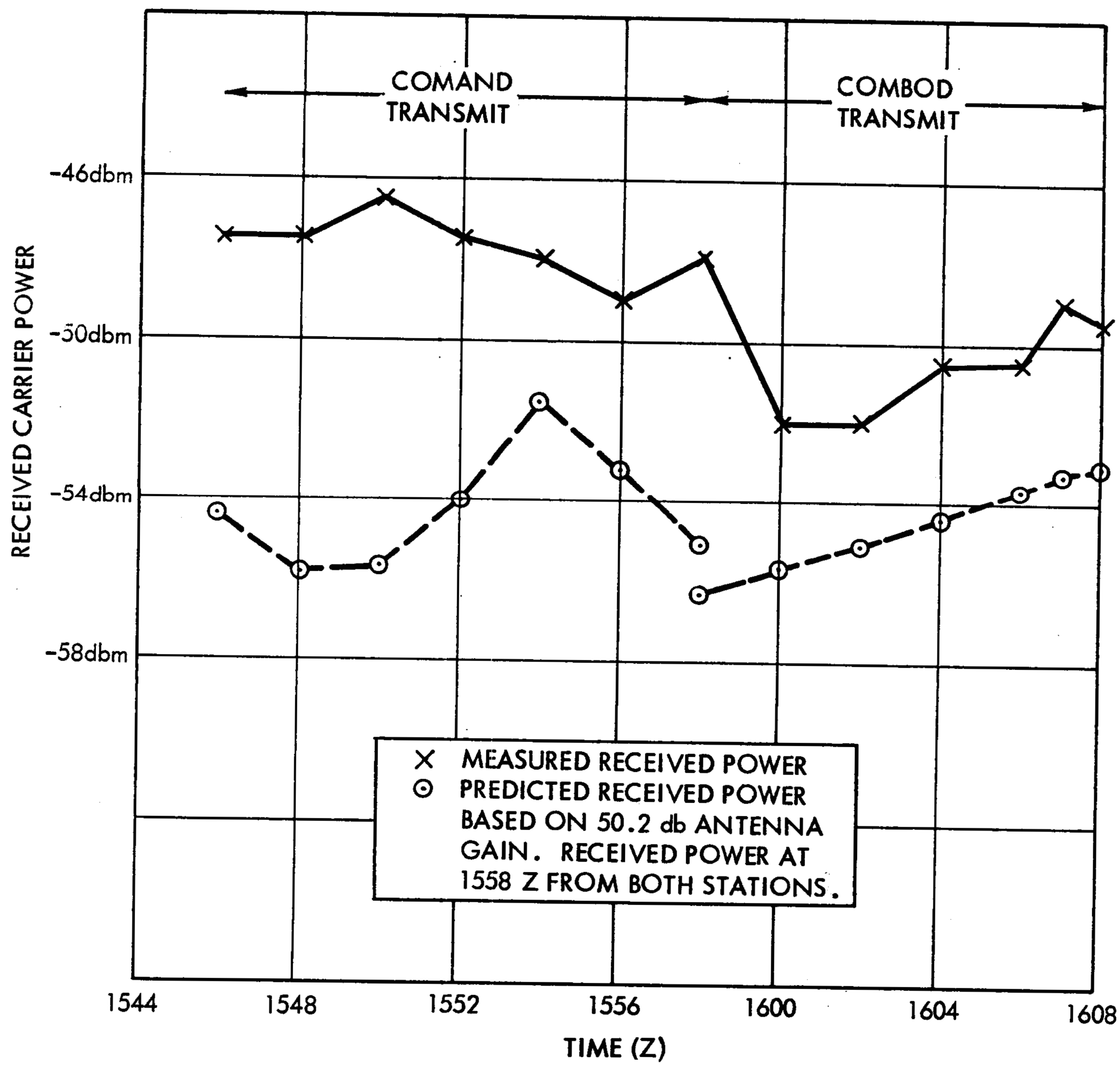


Figure 19. Spacecraft Received Carrier Power, Rev 200, 8 January 1963

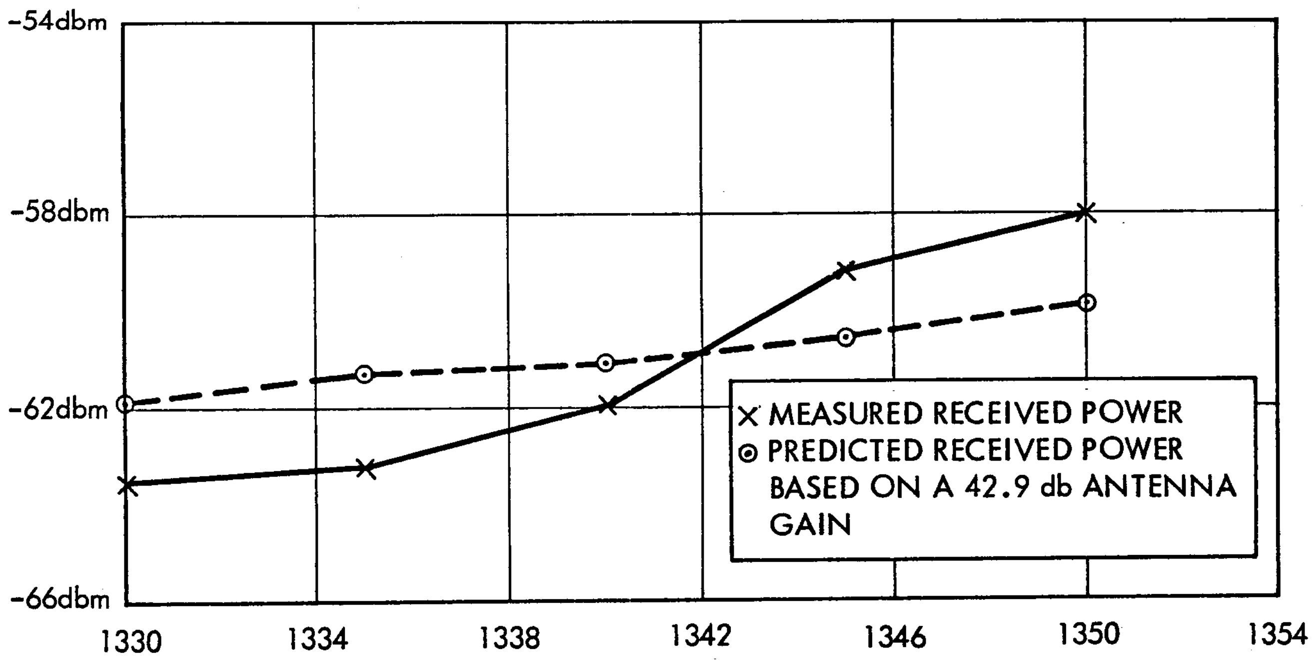
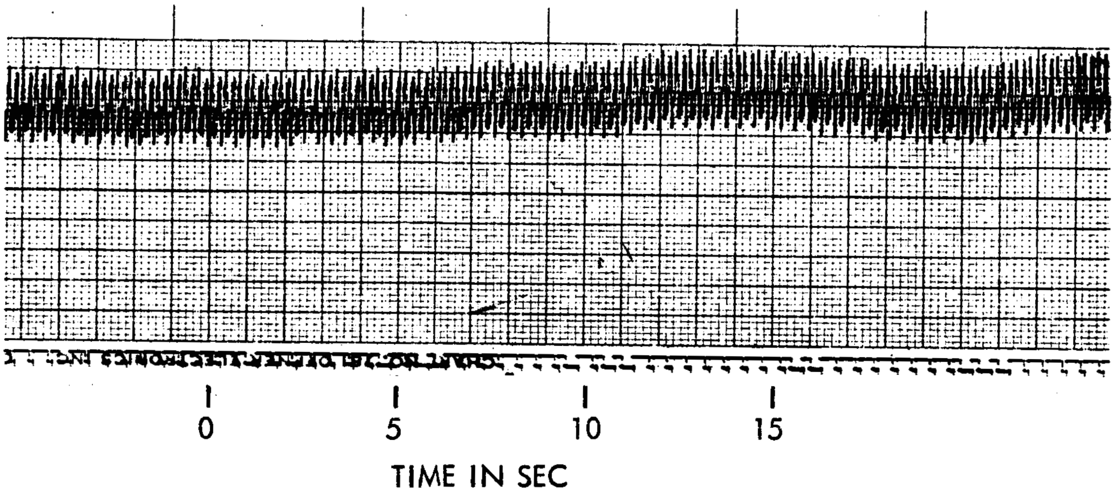


Figure 20. Spacecraft Received Carrier Power, COMCON Transmitting
Rev 565, 24 February 1963



SIGNAL STRENGTH	−98 dbm
SPIN VARIATION	±1 db
SPIN RATE	150 rpm

Figure 21. Typical Received Carrier Signal Showing Spin Variations COMCON Rev 565

II. G. 1. Baseband Doppler Shift

This measurement determines doppler shift at baseband. The test may be performed using a single frequency tone at baseband. The frequency of the received tone would then be compared to that of the transmitted tone.

The only measurement was performed by COMBOD during Rev 332. The results were reported to agree with predictions. No test procedures or quantitative results are known.

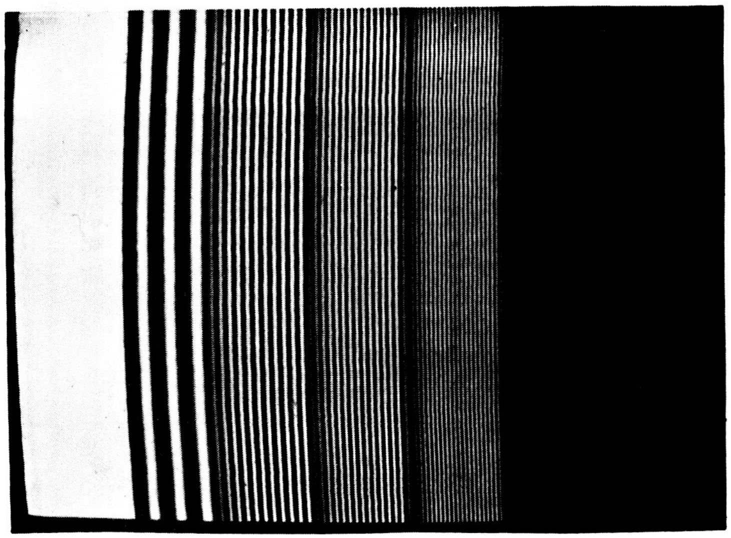
II. H. 1. <u>Television Tests</u>

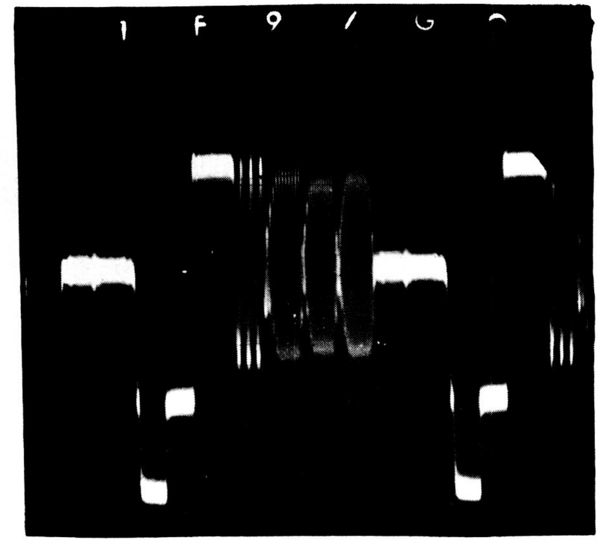
This measurement provides a basis for subjective evaluation of television transmission performance. Video test patterns and signals are transmitted. Both oscilloscope and monitor presentations are examined for distortion. The test has been performed both with and without pre-emphases.

A comprehensive set of test photographs received from COMHIL is presented in Figures 22 to 25. Figure 22 shows both monitor and oscilloscope presentations of a multi-burst signal. The dc step is followed by bursts of 0.5, 1.5, 2.0, 3.0, 3.6, and 4.2 mc. Both sets of photographs were made with a 3.2 mc baseband, so that the two highest frequency bursts are heavily attenuated. The upper frequencies appear to be attenuated more severely when pre-emphasis is used. The use of pre-emphasis increases the overshoot following rapid transitions. Figure 23 shows a NASA test pattern with a resolution of 350-400 lines. The actual monitor presentation may have indicated better resolution which was lost in the photographic process. Figure 24 shows a cross pattern and a black window pattern. Figure 25 shows two slides which represent more typical video material. Picture quality is excellent.

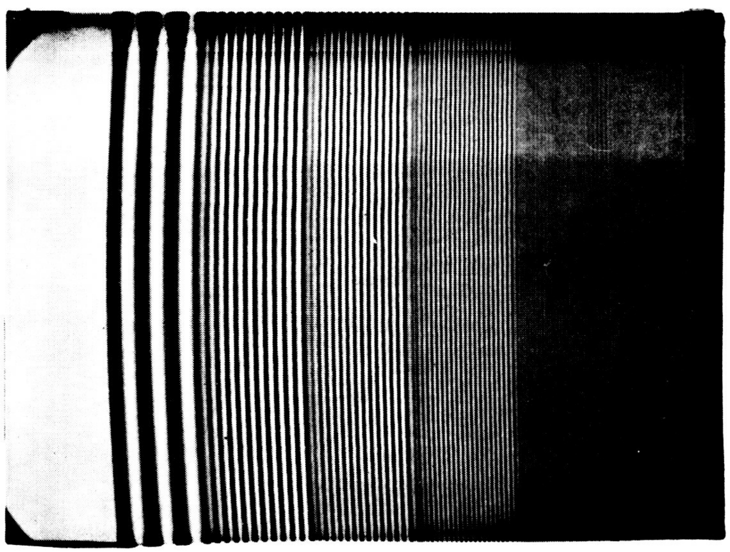
The overshoot following abrupt transitions is a function of demodulator bandwidth and is accentuated by the use of pre-emphasis.

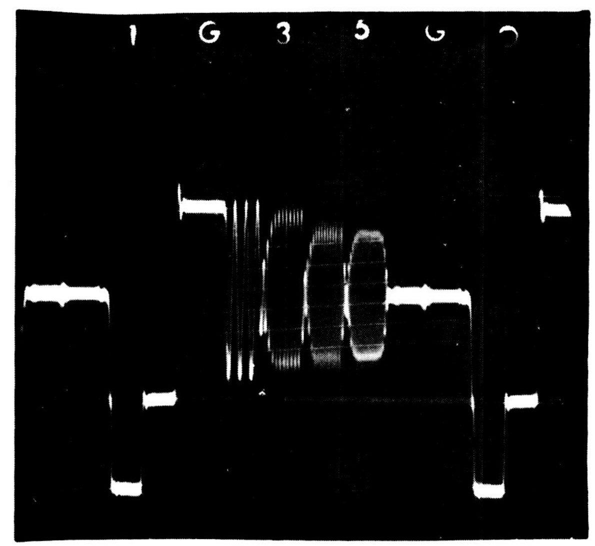
Figure 26 shows two test patterns received at COMCON during Rev 200 from COMBOD and COMAND. Figure 27 presents pictures received at COMMOJ with COMCON transmitting on Rev 565. A test pattern, a pulse-and-bar signal, and the NASA seal are shown. Picture quality appears good.





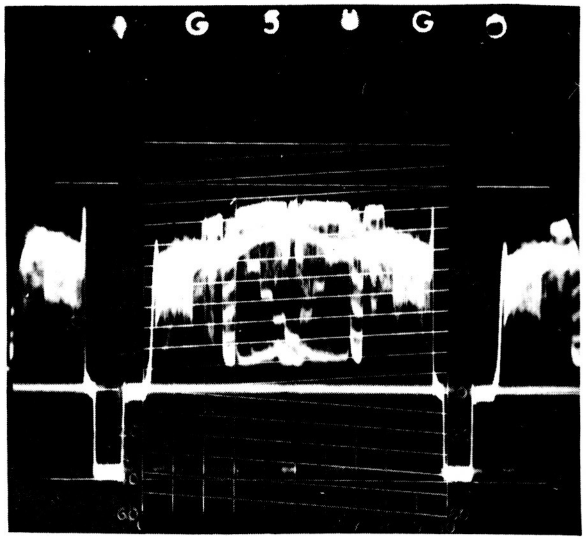
Multiburst Signal, Rev 176: no pre-emphasis, pre-modulation and post-detection bandwidth 3.2 mc, D.T.V.B. demodulator

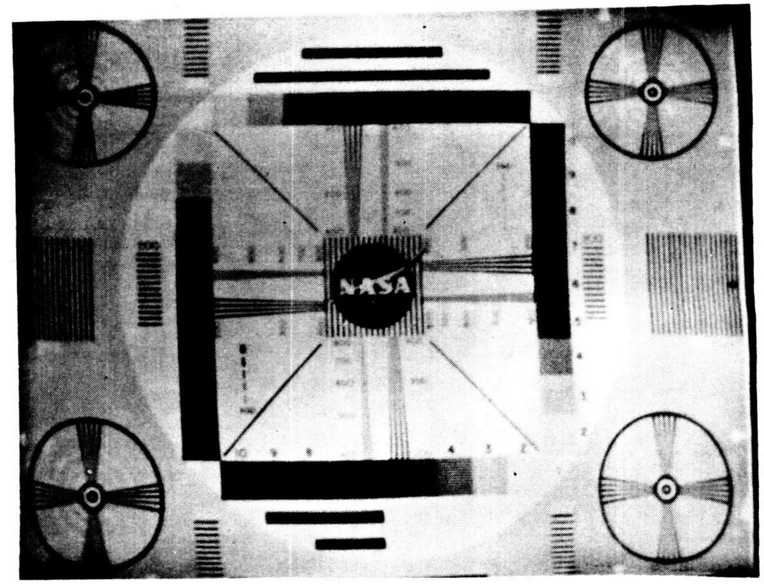




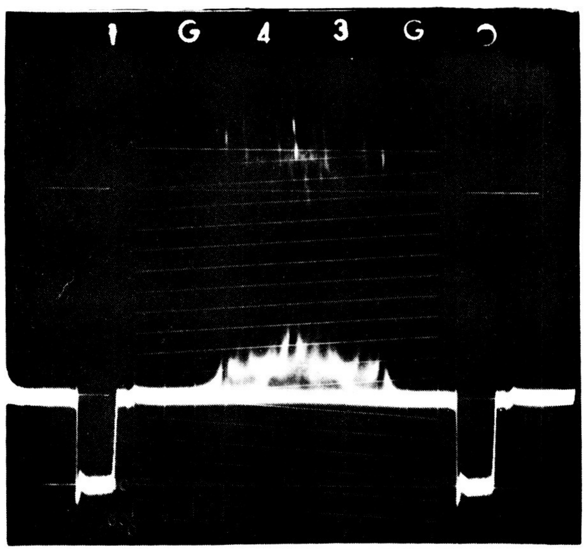
Multiburst Signal, Rev 206: 525-line pre-emphasis, pre-modulation and post-detection bandwidth 3.2 mc, D.T.V.B. demodulator

Figure 22. Television Tests, COMHIL



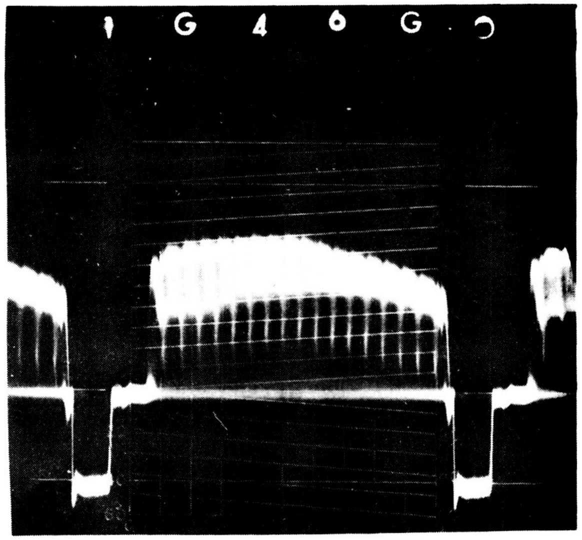


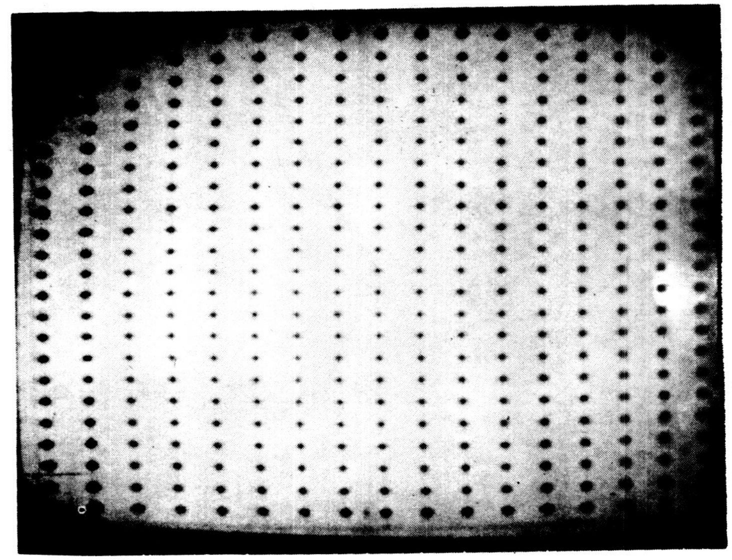
NASA Test Slide: 525-line pre-emphasis, 3.2 mc baseband width, D. T. V. B. demodulator



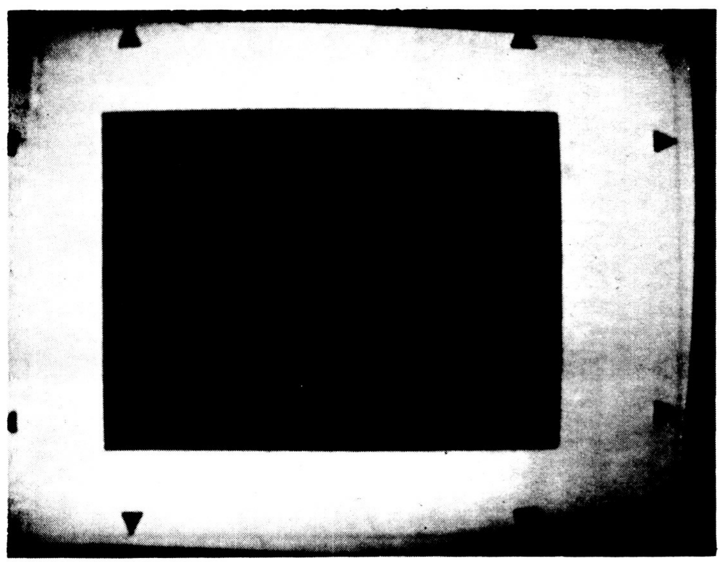
GPO Crest

Figure 23. Television Tests, COMHIL, Rev 206





Cross Pattern: 525-line pre-emphasis, 3.2 mc baseband width, D. T. V. B. demodulator



Black Window Pattern
525-line pre_

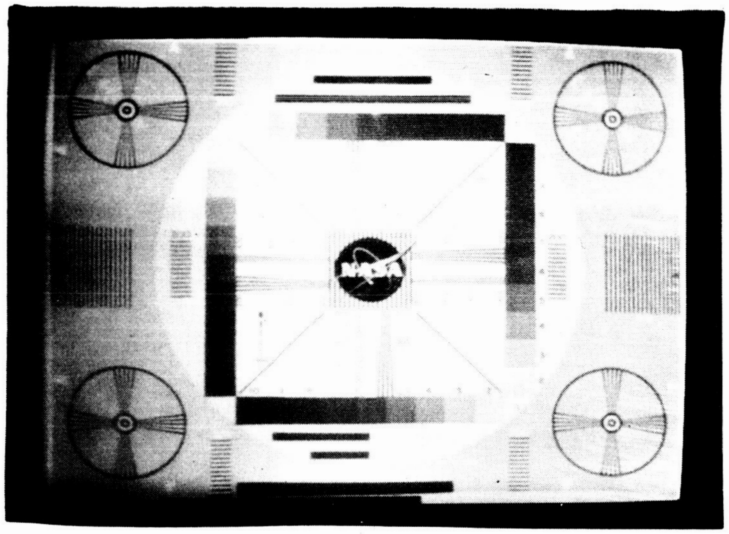
Black Window Pattern
525-line pre-emphasis
3.2 mc baseband width
D. T. V. B. demodulator

Figure 24. Television Tests, COMHIL, Rev 206

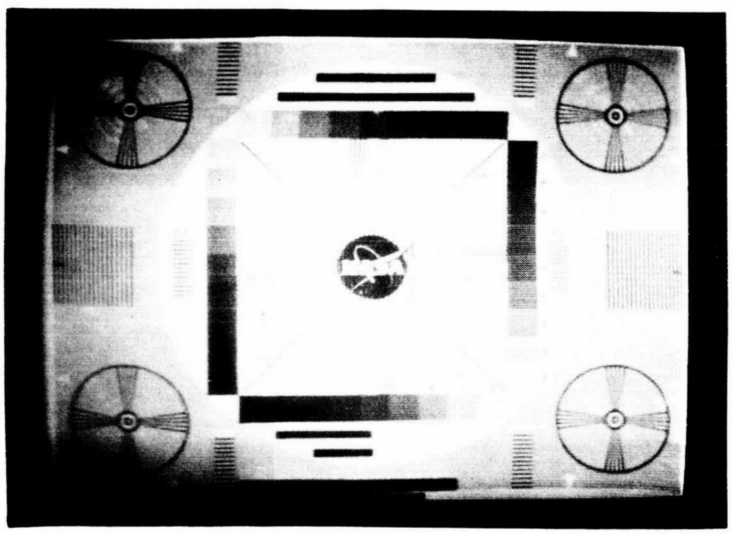
Rev 206

Rev 184

Figure 25. Television Tests, COMHIL

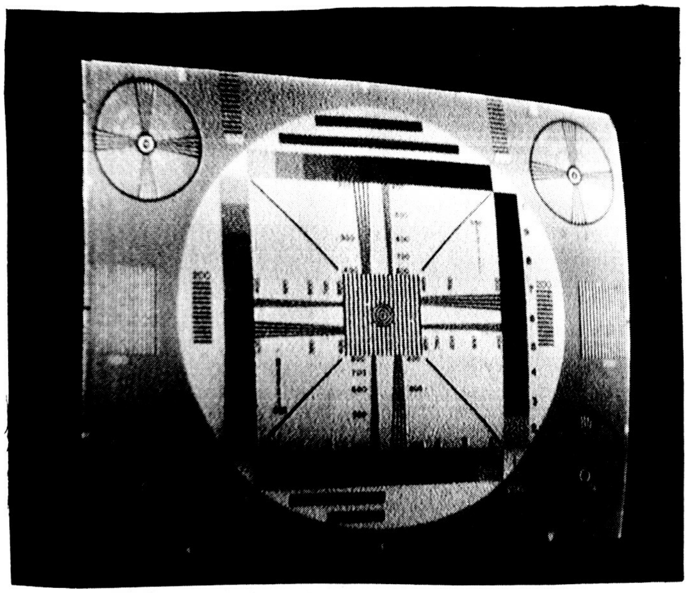


COMBOD transmitting



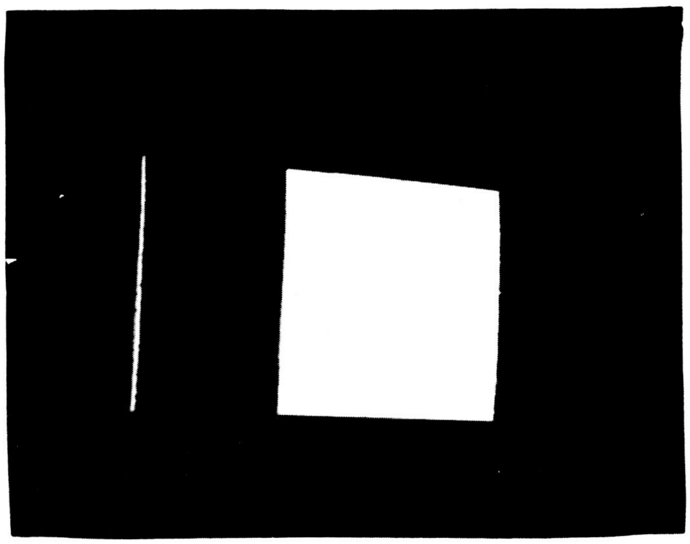
COMAND transmitting

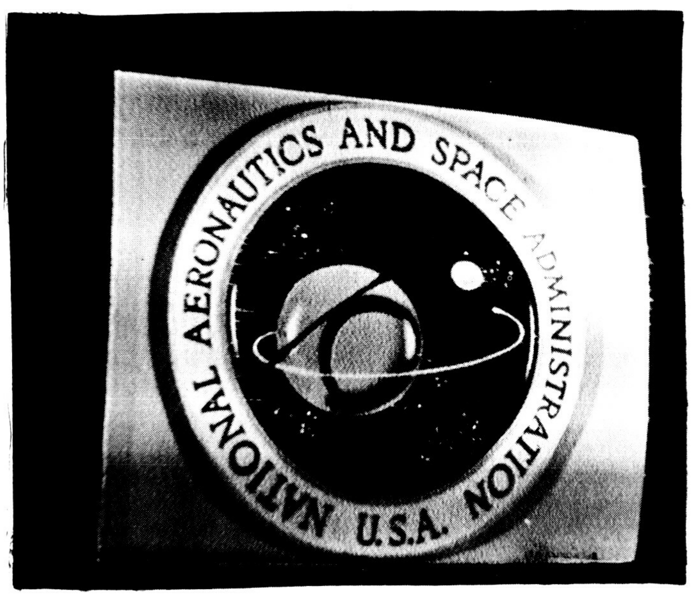
Figure 26. Television Tests, COMCON, Rev 200



Test Pattern

Pulse and Bar
Waveform





NASA Seal

Figure 27. Television Tests, COMMOJ, Rev 565 (phase-lock demodulator)

II. I. 2. Intermodulation - Cross Modulation Noise (Noise Loading)

The purpose of this test is to determine the level of intermodulation noise in the telephone channels under conditions similar to actual telephone loading conditions. The white-noise signal is used to simulate the loading imposed on the Relay system by the active telephone channels. In an FDM system the nonlinear or intermodulation noise is the unintelligible crosstalk produced in a specific channel due to harmonics and intermodulation products of the signals present in the other channels. The Experiment Plan calls for noise loading tests to simulate 60, 120, 300, and 600 telephone channels. It is desirable for the tests to be performed both with and without pre-emphasis.

The primary experiment of concern here is the 300-channel test with pre-emphasis. The Relay I performance objective was to accommodate this one-way multichannel telephony signal with an intermodulation noise level no greater than 7500 pw (psophometrically weighted) in the worst channel.

For the 300-channel test the baseband from 60 kc to 1300 kc is loaded with the white noise signal except for the measurement channels, which are clear. At the output of the system, the noise in the originally clear measurement channels is the sum of the intermodulation noise and the thermal noise of the system. Thermal noise must be subtracted to obtain the nonlinear noise resulting from transmission over the link.

The Noise Power Ratio, defined as the ratio of the level of noise in the freely transmitted band to that in the measurement channels, can be converted to psophometrically weighted noise power in a telephone channel by the formula:

$$N_{pw} = \frac{3.1 \, P_{eq}}{10^{0.25}(NPR) \; 10^{-12} \; (F_2 - F_1)}$$

NPR = Noise Power Ratio

N_{pw} = Psophometrically weighted noise power in picowatts referred to zero relative level.

P_{eq} = Equivalent white Gaussian noise power extending from F_1 to F_2 in milliwatts.

Without pre-emphasis the nonlinear noise should peak in either the highest or lowest channel. When pre-emphasis is used the nonlinear noise might peak most anywhere in the baseband depending upon the types of distortions which predominate.

Figure 28 gives N_{pw} as a function of NPR for 60, 120, 300 and 600 channels. Table 6 gives the results of the wideband noise loading tests that have been reported to date. The level of intermodulation noise measured in each of these cases differs considerably from the Relay I objective of 7500 pw. The COMBOD results indicate a level of intermodulation noise 5 db above the performance objective of 7500 pw. The COMHIL test was performed for 600 channels and at a deviation 4.5 times the specified Relay I deviation. This results in a 34-mc signal bandwidth to be accommodated in the spacecraft-to-ground link, which has a nominal bandwidth of 25 mc. The intermodulation noise is therefore significantly increased, as the tabulated results indicate. The RCA test results taken before launch indicate an expected spacecraft contribution of 2300 pw in the tope channel. The limited data available makes it impossible to conclude whether or not the system objective of 7500 pw for 300-channel loading is met by the various links.

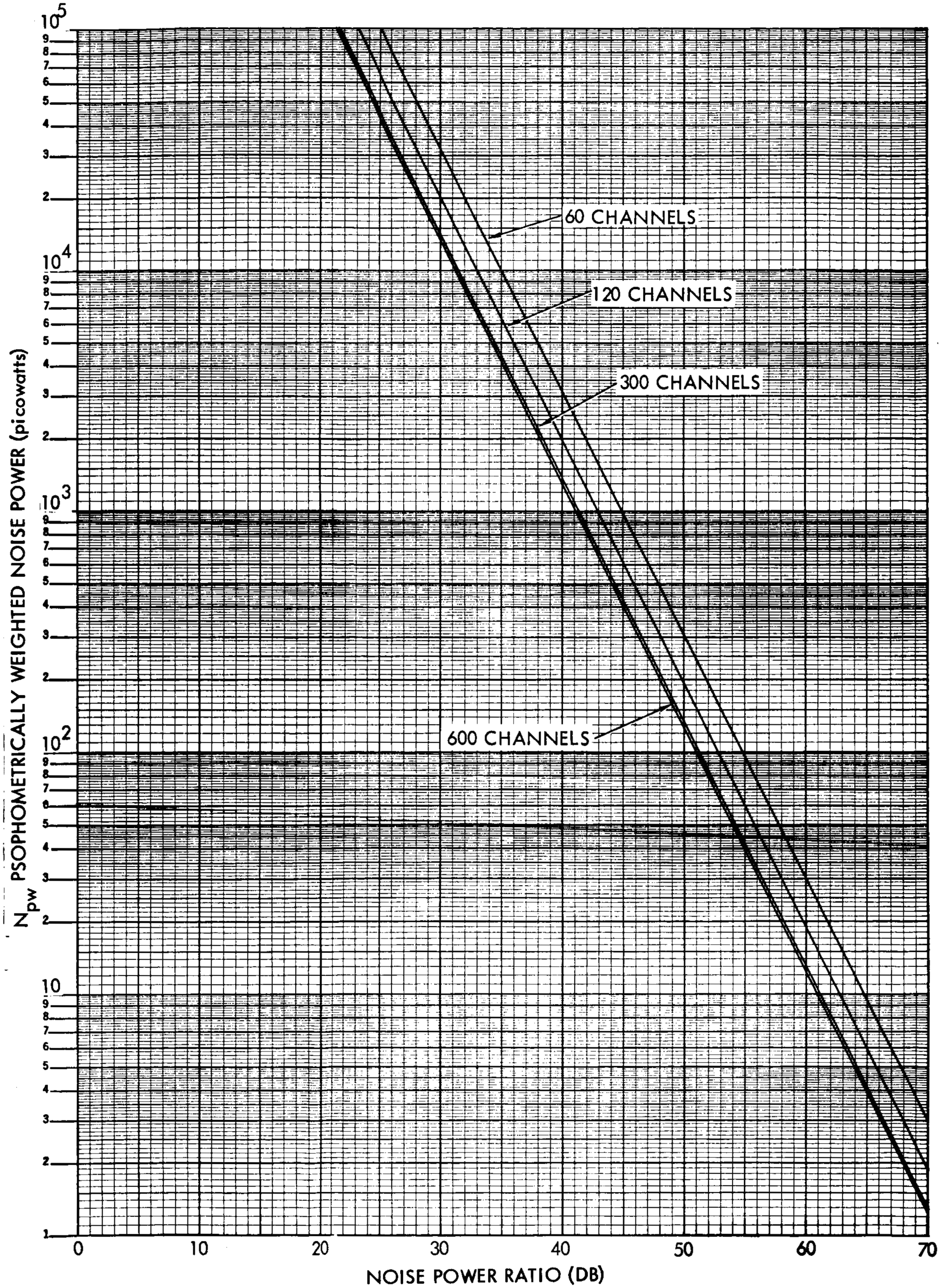


Figure 28. N_{pw} as a Function of Noise Power Ratio (**Wideband Telephony**)

Table 6

Noise Loading Tests

COMBOD -- COMBOD Rev 223 300 Channels with Pre-emphasis			COMHIL -- COMHIL Rev 301 600 Channels without Pre-emphasis		
Channel	NPR (db)	N_{pw} (Picowatts)	Channel	NPR (db)	N_{pw} (Picowatts)
70 kc	27.25	25,000	534 kc	28.2	20,000
			1248 kc	25	43,000
1248 kc	28.25	20,000	2438 kc	23	66,000

RCA Test Data

300 Channel Noise Loading
(with Pre-emphasis Correction Factor)

Temp.	Channel	NPR (db)	N_{pw} (picowatts)
25° C	1248 kc	40.2	1230
0° C	1248 kc	37.5	2290

III. NARROWBAND EXPERIMENTS

III. A. 1. Insertion Gain

The purpose of this test is to determine the system insertion gain and gain stability for several telephone channels. An audio sine wave is applied to the inputs of various telephone channels. After transmission and subsequent reception, the channels are demodulated and the received levels measured. The primary importance of this test is in establishing a reference level and in checking the compatibility of the baseband equipment at the transmitter and receiver in terms of signal level. The level is especially important at the transmitter to provide the desired frequency deviation.

The test signals employed have generally been 1-kc tones inserted in the lowest (12-16 kc) and highest (56-60 kc) channels with a voice narration of the experiment on channel 4. Loading of all channels (except 4) and subsequent measurement of insertion gain variations across the baseband was performed numerous times. The measurements of insertion gain have varied considerably depending upon the ground station link involved. For the most part there have been only negligible gain variations within a given measurement period.

For specific passes a maximum short-period (1 sec.) variation of 2.6 db was reported, but the usual report has been 0 db. Medium-period variations as high as 0.7 db have been reported, but the average reported has been less than 0.4 db. Ripples in the gain of 1 to 1.5 cps frequency were reported several times. There has been considerable variation between the gain for the lowest and highest channel, which is partly attributable to inconsistency in the use of pre-emphasis and de-emphasis networks. With proper calibration it has been possible to maintain the variations in insertion gain for the various channels and with respect to time within the range of -1 db to +1 db. A summary of typical insertion gain values is given in Table 7.

Table 7

Typical Insertion Gain Measurements Reported

Link (Trans - Rec)	Rev	Insertion Gain Measurement Channel 1	Channel 12
COMNUT - COMHIL	222	-5.7 db	+1.3 db
COMRIO - COMHIL	253	-15.5 db	-5.3 db
COMNUT - COMNUT	284	-0.5 db	-0.6 db
COMHIL - COMNUT	253	+3 db	+3 db
COMBOD - COMNUT	199	+1.3 db	-4.8 db
COMAND - COMNUT	214	+1.5 db	-2.5 db
COMRIO - COMNUT	322	-0.1 db	0 db
COMBOD - COMBOD	199	-2.0 db	-0.4 db
COMAND - COMBOD	254	+2.4 db	+3.0 db
COMHIL - COMBOD	215	+1.5 db	+0.5 db
COMNUT - COMBOD	262	-3 db	+2 db
COMNUT - COMTEL	416	-0.6 db	0 db
COMRIO - COMTEL	229	-1.0 db	+0.3 db
COMBOD - COMTEL	315		-0.5 db
COMAND - COMTEL	221	-1.7 db	+2.0 db
COMNUT - COMRIO	260	-4 db	-4.5 db

III. B. 1. Continuous Random Noise Measurement

The purpose of this test is to determine the level of continuous random noise or thermal noise in the telephone channels. Thermal noise objective for the link, along with the number of channels to be transmitted, determines the initial design requirements for the system - transmitter power for ground station and spacecraft, the frequency deviations and bandwidths. Therefore, the thermal noise performance of the Relay I system is an indication of the degree to which the general parameters of the system meet the original design objectives. For an FM communications system with the receiver operating above threshold the thermal noise power spectral density at the baseband output is parabolic (increases at 6 db per octave). Therefore, with the receiver above threshold the thermal noise should be highest in the top channel. The use of pre-emphasis and de-emphasis networks decreases the noise in the higher channels and tends to equalize the thermal noise across the baseband.

In the measurement of thermal noise in a telephone channel a tone is generally applied intermittently to provide a reference level for the measurement. Typical continuous random noise results for the various ground stations for the narrowband mode are given in Table 8. Also given is the thermal noise objective for the stations. Figures 29 and 30 show variations in the continuous random noise level as a function of time as reported by COMHIL. Figure 29 demonstrates a fairly large variation in noise level over a pass, while Figure 30 demonstrates the variation in noise level as a function of channel position when pre-emphasis is not used.

Table 8

Continuous Random Noise (Psophometrically-weighted picowatts at zero relative level)

Station	Rev No.	Pre-emphasis	Channel No.	Objective N_{pw} (picowatts)	Measured N_{pw} (picowatts)
COMNUT	284	Yes	1	50,000	50,200
			12	50,000	31,600
COMHIL	261	No	2	7,500	2,200
			5	7,500	2,700
			11	7,500	7,000
COMTEL	384	Yes	7	50,000	35,000
			9	50,000	40,000
			12	50,000	35,000
COMBOD	199	Yes	1	7,500	45,600
			6	7,500	27,600
			12	7,500	11,000

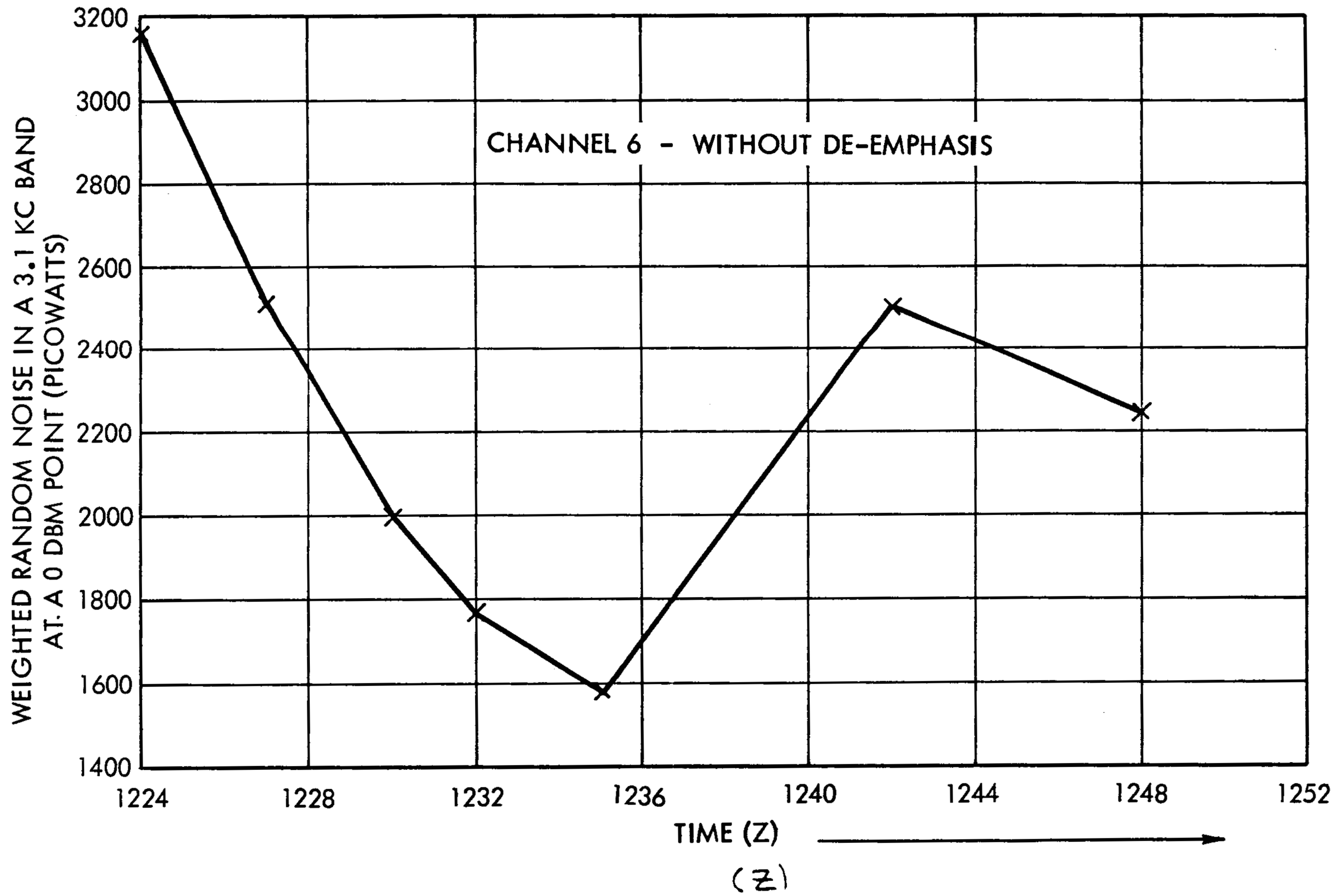


Figure 29. Weighted Random Noise, COMHIL, Rev 199

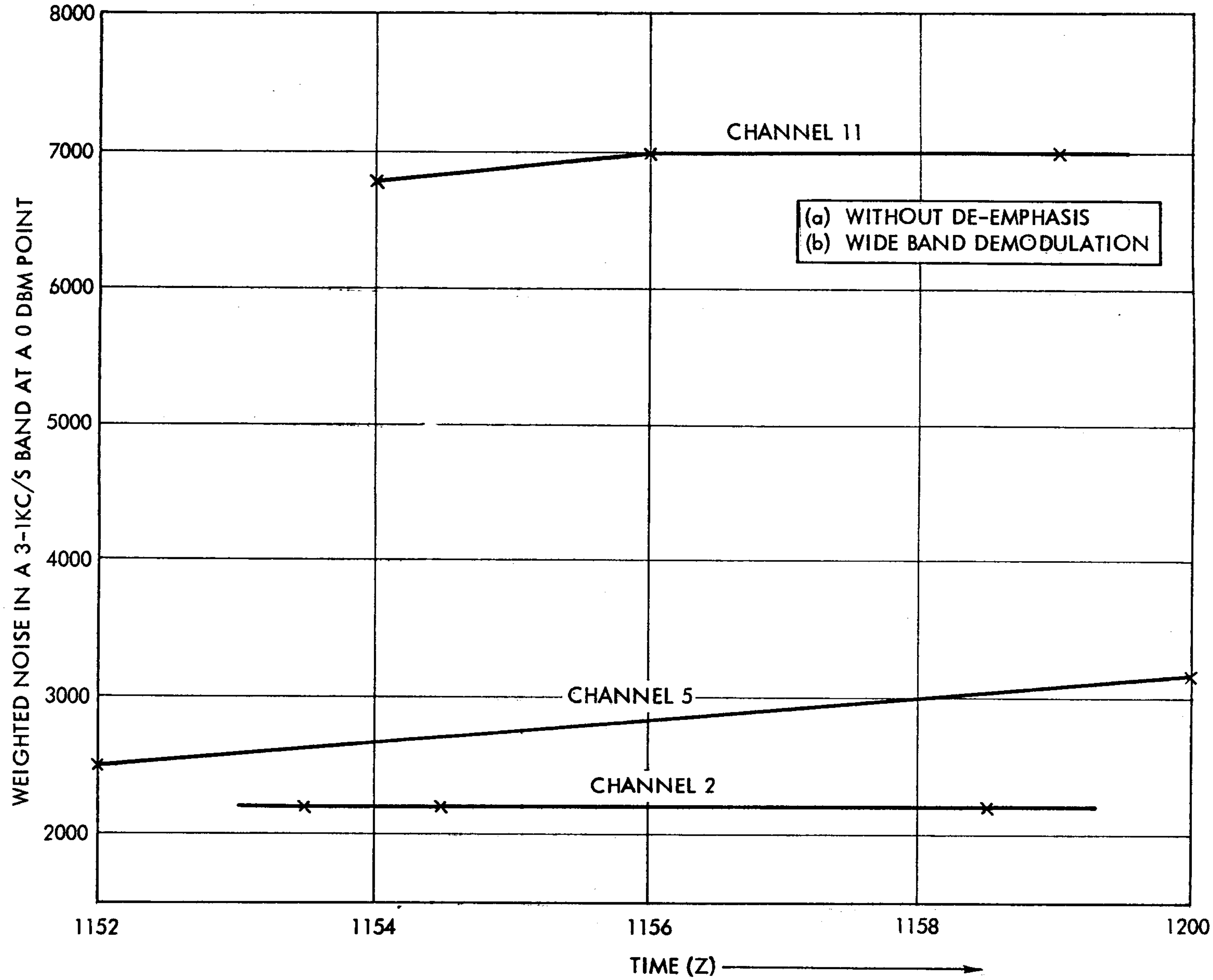


Figure 30. Weighted Random Noise vs. Channel Position, COMHIL, Rev 261

III. B. 3. Periodic Noise Measurement

The purpose of the test is to determine the relative amplitude of the periodic noise introduced into the link. The search for noise components at discrete frequencies is performed by using a tunable voltmeter over the range from 60 cps to 60 kc. Although R1-0000 contains no performance objective for periodic noise for the narrowband mode, a desirable signal-to-noise ratio would be approximately 50 db.

The measurement reported from COMNUT on revolution 393 indicates a minimum signal-to-periodic-noise ratio of 56 db over the frequency range from 10 cps to 100 kc. Discrete frequency noise components were observed at 16 kc and 48 kc with a level of -76 db and -56 db, respectively, relative to a full-load test tone.

III. C. 1. Baseband Bandpass Characteristics

The purpose of this test is to determine the useful system baseband. A series of tones of amplitude equal to the full-load tone level for Group A (12 kc to 60 kc) and of various frequencies from 10 kc to 500 kc is transmitted in sequence. The level of the tones is measured at the receiver output to obtain a frequency response characteristic.

The following results have been reported:

COMNUT to COMTEL (Rev 191)

Frequency (kc)	10	20	30	40	50	80	100	125	150
Level (db)	0	0	0	0	0	0	0	0	-2.5 db

COMNUT to COMNUT (Rev 191)

Frequency (kc)	20	40	60	80	100	120	140	160	250	350	500
Level (db)	-1.4	-1.2	-1.1	-1.3	-1.1	-1.1	-1.0	-1.5	+0.5	-1.5	-5.5

These data indicate the baseband frequency response over the 12 kc to 108 kc range of interest to be flat within 0.3 db and to be fairly flat considerably beyond this region. The COMNUT results correlate well with the response characteristic measured before launch. Qualitative data from COMBOD (Rev 315) in looped configuration indicates excellent response characteristic.

III. E. Received Carrier Power

The purpose of this test is to measure and record the level of the received carrier power at the various ground stations. The results of this experiment are to be compared to calculated values of received carrier power to determine the effects of satellite attitude, ground station performance, weather, and satellite communication equipment performance on carrier level. Generally, the receiver AGC voltage or a proportion voltage has been recorded to provide a continuous record of the received carrier power variations. Calibration curves taken on the equipment allow the conversion to power level.

The value of predicted power at any time can be calculated from the following and compared to the measured levels.

$$P_i = P_o - a_1 + A_1 - A_2$$

P_i = Received carrier power in dbm

P_o = TWT power output in dbm

a_1 = 1 db = Spacecraft cable and diplexer losses

A_1 = Spacecraft antenna gain in db

a_2 = Path attenuation from spacecraft antenna to ground receiving antenna (free space calculation)

Table 9 gives range of narrowband received carrier powers at the various ground stations and typical variations over a pass. Figure 31 gives the variation in measured and predicted carrier powers at COMHIL for revolution 199.

Table 9

Measured Narrowband Received Carrier Power[1]

Receiving Station	Minimum Reported Value	Maximum Reported Value	Typical Variation over one Rev	Expected[2] Performance (5000 n. m.)
COMAND	-100 dbm	-83 dbm	3-4 db	-88.8 dbm
COMBOD	-95 dbm	-83 dbm	3 db	-93.6 dbm
COMNUT	-110 dbm	-98 dbm	4-5 db	-100.1 dbm
COMHIL[3]	-100 dbm	-86 dbm	4-5 db	-89.8 dbm
COMTEL	-113 dbm	-100 dbm	3-4 db	-102.7 dbm
COMRIO	-116 dbm	-99 dbm	3 db	-103.0 dbm

Notes

1. Based on values from operations reports.
2. Taken from R1-0000 Project Relay I System Requirements and based upon a maximum range of 5,000 nautical miles (9,266 kilometers.) Some reported measurements were made at ranges greater than this nominal limit.
3. COMHIL results are a measurement of the sum of the powers in the two narrowband carriers.

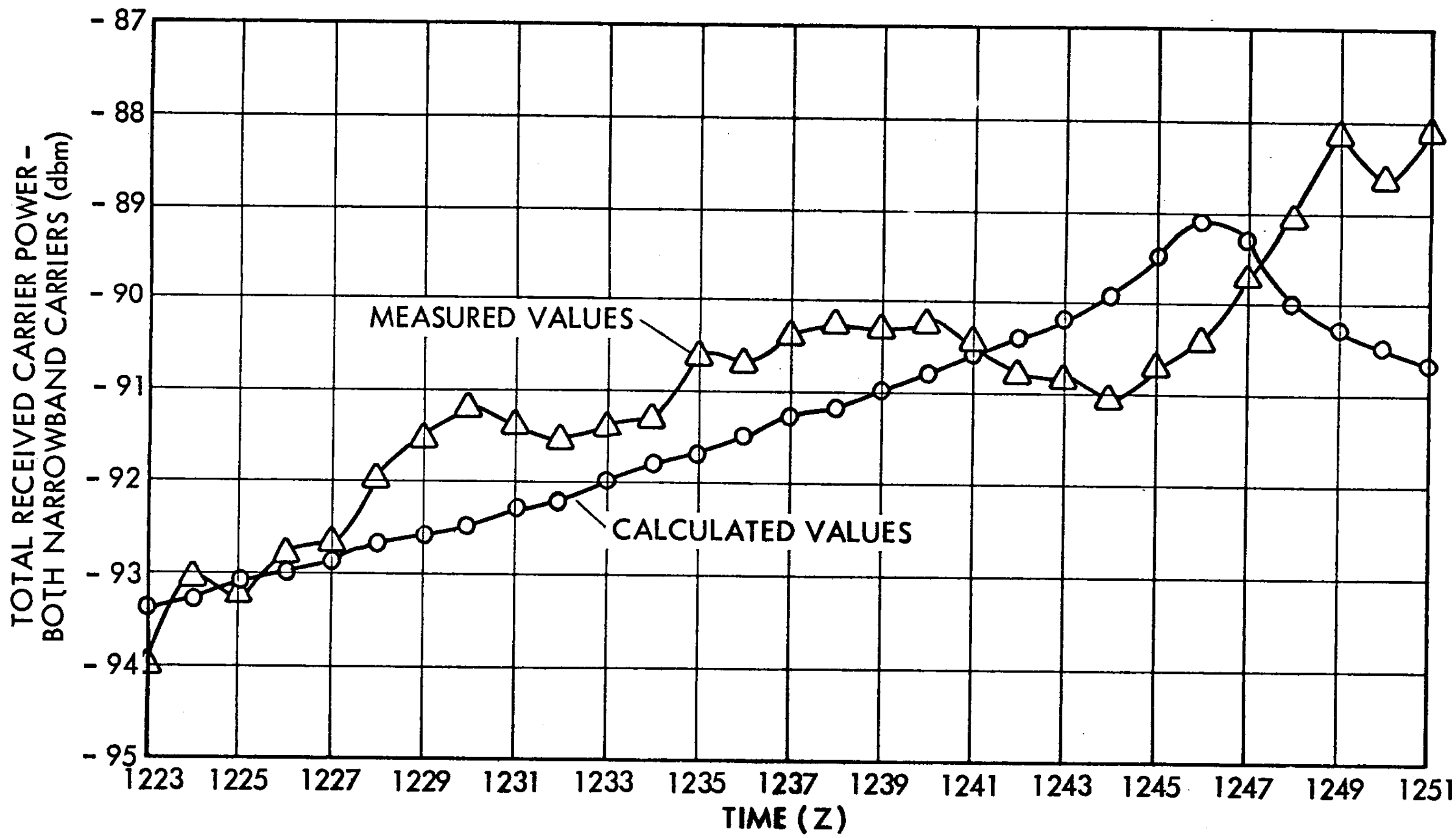


Figure 31. Narrowband Received Carrier Power, COMHIL, Rev 199

III. F. 1. Intermodulation-Harmonic Performance

The purpose of this test is to determine the linearity of transmission for the two-way twelve-channel mode of operation by examining the harmonics and crossmodulation sum and difference frequencies generated from an input of two tones. Since the system is describable in terms of second and third order nonlinearities to a reasonable degree of accuracy, the principal frequencies generated from tones of frequency f_1 and f_2 are: d-c, $2f_1$, $2f_2$, $f_1 + f_2$, $f_1 - f_2$, $3f_1$, $3f_2$, $2f_1 + f_2$, $2f_1 - f_2$, $2f_2 + f_1$, $2f_2 - f_1$. The existence of additional frequency components such as $4f_1$, $4f_2$, $5f_1$, $5f_2$, are an indication of the degree to which second and third order nonlinearities (e.g., linear and parabolic envelope delay) are sufficient to describe the system.

When no de-emphasis is present at the output of the receiver, the following can be concluded from a relatively simple analytical derivation. Baseband amplitude nonlinearities cause pairs of equal-amplitude sum and difference frequency components of each order: $f_1 + f_2$ and $f_1 - f_2$, $2f_1 + f_2$ and $2f_1 - f_2$, and $2f_2 + f_1$ and $2f_2 - f_1$. Phase nonlinearities cause frequency components which have an amplitude proportional to the frequency of the individual components. Therefore, the difference in amplitude between the $f_1 + f_2$ frequency component and the $f_1 - f_2$ component is an indication of the linear envelope delay and the difference in amplitude between the $2f_2 + f_1$ and the $2f_2 - f_1$ components is an indication of the parabolic envelope delay. The portion of these amplitude measurements which is not proportional to frequency is related to the second order and third order baseband nonlinearities.

Therefore, given the amplitudes of the intermodulation frequency components generated from an input signal of two tones, a set of coefficients can be derived which approximate the system nonlinearities by second and third order terms. From these coefficients linear and parabolic delay and intermodulation noise levels can be predicted and correlated with the results of delay measurement and noise loading tests.* When a de-emphasis network is present, the alteration of the amplitudes must be taken into account in the above considerations.

*D. P. Sullivan, "Intermodulation Distortion Study for FM Communications Satellite Systems," Space Technology Laboratories, Inc., Document No. 8614-6030-RU-000, prepared for NASA under Contract No. NAS5-1302.

The levels of the intermodulation noise products for the experiments reported thus far are given in Table 10. An analysis of the link nonlinearity based upon the two-tone test results will be included in the final report on Relay I, provided sufficient data is available for a meaningful evaluation. No system objective has been placed on the allowable level of the various frequency components generated in a two-tone test for Relay I.

Table 10

Intermodulation Noise Harmonics

	COMNUT to COMNUT			COMNUT to COMTEL			COMAND to COMTEL		
	Rev 416 f_1 = 20 kc f_2 = 15 kc	Input Level A_1 = 10.7 dbm0 A_2 = 10.0 dbm0		Rev 416 f_1 = 20 kc f_2 = 15 kc	Input Level A_1 = 10.7 dbm0 A_2 = 10.0 dbm0		Rev 221 f_1 = 33 kc f_2 = 13 kc	A_1 = 7.2 dbm0 A_2 = 5.3 dbm0	
		With Pre-emphasis (performed)	Without Pre-emphasis (derived)		With Pre-emphasis (performed)	Without Pre-emphasis (derived)		With Pre-emphasis (performed)	Without Pre-emphasis (derived)
$2f_1$	40 kc			40 kc	-47.6 dbm0	-47.8 dbm0	66 kc		
$2f_2$	30 kc			30 kc	-42.3 dbm0	-41.8 dbm0	26 kc		No measurable component
$f_1 + f_2$	35 kc	-55 dbm0	-56.1 dbm0	35 kc	-46.2 dbm0	-47.3 dbm0	46 kc	-42.2 dbm0	-40.6 dbm0
$f_1 - f_2$	5 kc			5 kc	-45.1 dbm0	-48.9 dbm0	20 kc	-37.5 dbm0	-40.0 dbm0
$3f_1$	60 kc			60 kc			99 kc		
$3f_2$	45 kc			45 kc			39 kc		
$2f_1 + f_2$	55 kc	-40 dbm0	-36.7 dbm0	55 kc			79 kc		
$2f_1 - f_2$	25 kc	-37 dbm0	-38.8 dbm0	25 kc			53 kc		
$2f_2 + f_1$	50 kc			50 kc			59 kc		
$2f_2 - f_1$	10 kc	-15 dbm0	-18.5 dbm0	10 kc			7 kc		
Other frequency components							14 kc 16 kc 24 kc 32 kc 34 kc 35 kc 36 kc		-48.6 dbm0 -39.7 dbm0 -40.2 dbm0 -39.0 dbm0 -38.5 dbm0 -33.0 dbm0 -43.4 dbm0

III. F. 2. Intermodulation - Noise Loading

The purpose of this test is to determine the level of intermodulation noise in the telephone channels under conditions similar to the actual telephone loading conditions. The white-noise signal is used to simulate the loading imposed on the Relay system by the 12 active telephone channels. In an FDM system the nonlinear or intermodulation noise is the unintelligible crosstalk produced in a specific channel due to harmonics and intermodulation products of the signals present in the other channels. For this test the baseband from 12 kc to 60 kc is loaded with the white noise signal except for the measurement channel, which is clear (noise should be suppressed at least 80 db). At the output of the system, the noise in the originally clear measurement channel is the sum of the intermodulation noise and the thermal noise of the system. If the thermal noise is not negligible, then it must be subtracted to obtain the non-linear noise level resulting from transmission over the link.

The Noise Power Ratio, defined as the ratio of level of noise in the freely transmitted band to that in the measurement channels, can be converted to psophometrically weighted noise power in a telephone channel by the following:

$$N_{pw} = \frac{3.1\ P_{eq}}{10^{0.25}\ (NPR)\ 10^{-12}(F_2-F_1)}$$

NPR = Noise Power Ratio

N_{pw} = Psophometrically weighted noise power in picowatts referred to zero relative level.

P_{eq} = Equivalent white Gaussian noise power extending from F_1 to F_2 which the CCIR recommends to represent the multiplex of telephone channels at zero relative level. For 12 channels P_{eq} = 3.32 dbm0

Figure 32 gives N_{pw} as a function of NPR for 12 telephone channels. Table 11 gives the results of the noise loading tests that have been reported on to date. The level of intermodulation noise measured is considerably above the Relay I objective of 7500 pw. In all of the COMNUT results the center measurement channel has the highest noise level. When pre-emphasis is used, the intermodulation noise can peak at any point within the base-band depending upon the types of distortion which predominate. Without pre-emphasis the nonlinear noise should peak in either the highest channel or the lowest channel.

The results of the noise loading test can be correlated with the envelope delay distortion experiment (III D-1) and the harmonic performance experiment (III F-1). This will be done to the extent possible with the available data for the final report on Relay I.

Table 11

Intermodulation Noise Loading Measurements

	COMNUT to COMNUT Rev 284 With pre-emphasis		COMNUT to COMNUT Rev 393 With pre-emphasis		COMNUT to COMNUT Rev 416 With pre-emphasis		COMNUT to COMTEL Rev 416 With pre-emphasis			
Center Frequency of Channel	NPR (db)	N_{pw} Picowatts Psophometrically Weighted	NPR (db)	N_{pw} Picowatts Psophometrically Weighted	NPR (db)	N_{pw} Picowatts Psophometrically Weighted	NPR (db)	N_{pw} Intermodulation plus Thermal Picowatts Psophometrically Weighted	N_{pw} Thermal Picowatts Psophometrically Weighted	N_{pw} Intermodulation Picowatts Psophometrically Weighted
14 kc	39 db	9,500	31 db	60,000	36 db	19,000	36.2	18,000	11,200	6,800
34 kc	31 db	60,000	29 db	95,000	33 db	37,500	35.8	20,000	18,000	2,000
56 kc	34 db	30,000	32 db	47,500	34 db	30,000	35.2	22,500	22,500	-----

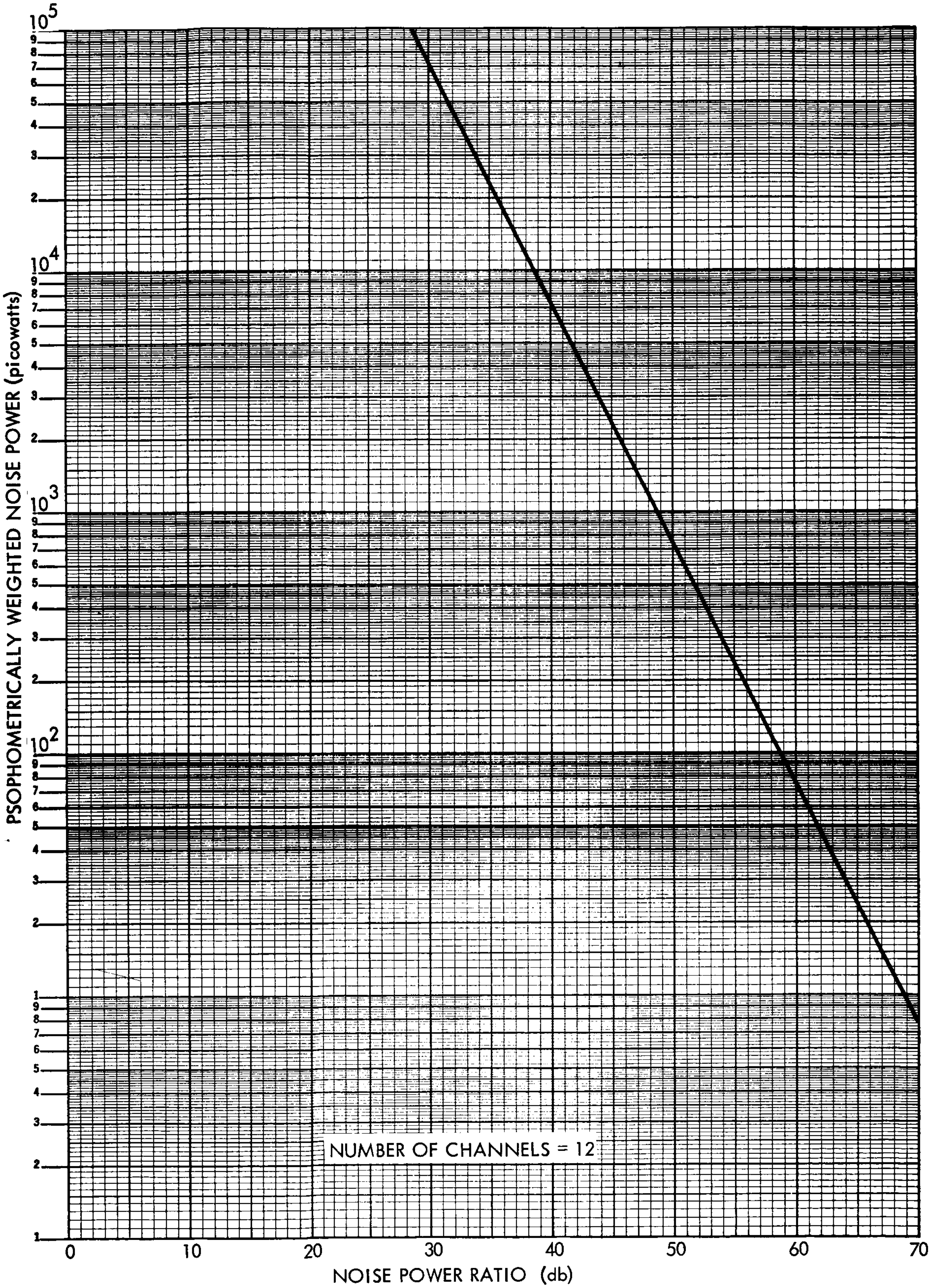


Figure 32. N_{pw} as a Function of Noise Power Ratio, Narrowband Operation

III. I. 1. Intelligible Crosstalk

The purpose of this test is to determine the level of intelligible crosstalk produced by the simultaneous presence of two r-f carriers within the Relay spacecraft. In the narrowband mode of two-way telephony the two signals, which are separated slightly in frequency, pass through the same r-f and i-f amplifiers in the satellite. Some of the PM(FM) on each of the signals is converted to AM on that same signal through imperfect limiting and from the sloped frequency-response characteristics of amplifiers. Through AM/PM conversion this AM on one carrier is transferred to PM on the other carrier. The effect is that the baseband of one carrier is transferred to the baseband of the other carrier at a low level. If the same baseband frequency range is employed in each direction, then a listener will hear in the background another telephone message - that message being transmitted in the channel slot where he is listening.

Intelligible crosstalk is considerably more annoying than thermal noise or intermodulation noise and has a more rigorous specification. The system objective for allowable crosstalk level for Relay I is -55 dbm0 for an interfering tone at zero relative level. Complementary channel operation relaxes this specification, since an echo is less annoying than another conversation.

The test for intelligible crosstalk is performed by modulating one narrowband carrier with a 100 kc tone and measuring the 100 kc frequency component present in the baseband of the other narrowband carrier. The results are given in dbm0, referred to a 1-milliwatt test tone modulating the opposite carrier. The actual level at which the test is performed is considerably higher than 0 dbm0, so that the crosstalk component can be more easily measured. The results reported to date are:

Station	Rev		Intelligible Crosstalk Level
COMNUT	199		-42.2 dbm0
COMBOD	199		-36 dbm0
COMAND	300	Same experiment	-53.3 dbm0
COMHIL	300		-49 dbm0
COMAND	300	Same experiment	-54.8 dbm0
COMHIL	300		-54.0 dbm0

The measurements conducted have shown frequency components to be present at harmonics of 100 kc, many of which have a considerably higher level than the basic 100 kc crosstalk (as high as -36 dbm0). These constitute intermodulation noise components which are not intelligible and which do not have a -55 dbm0 objective. However, this does indicate an increase in the intermodulation noise level when both carriers pass simultaneously through the satellite.

Prelaunch tests of the Relay spacecraft indicate an intelligible crosstalk level of less than -41 dbm0. The above data shows considerable variability in the measured level of intelligible crosstalk and indicates a possible failure to meet the system objective of -55 dbm0.

IV. DEMONSTRATION EXPERIMENTS

IV.A Television Demonstration

This test is intended to demonstrate the feasibility of transmitting quality monochrome television material with the associated audio material between Europe and the United States.

Demonstrations were successfully completed on 9 January during Rev 207, and on 19 January during Rev 285. Both demonstrations were transmitted from COMAND.

The 9 January demonstration consisted of a program dealing with the opening of the exhibition of the world famous painting, the "Mona Lisa", at the National Gallery of Art. The program material consisted of live studio shots and taped material depicting the opening ceremony on the evening of 8 January and people attending the exhibition on the morning of 9 January. The live material was of excellent quality and was received satisfactorily. The taped material was of a poorer quality and thus did not fully test the transmission system. Intermittent modulation or "hits" were reported from both COMAND and COMBOD beginning after ten minutes of the experiment period. The audio channel was received reasonably well. Photographs of material received at COMCON are presented in Figure 33 .

The demonstration of 19 January featured a program concerning the visit of Premier Amitore Fanfani of Italy to the United States. It was received both at COMHIL and COMTEL. The program concentrated on the Premier's visit to Chicago. Photographs of COMCON reception are presented in Figures 34a, 34b, 34c, and 34d. Figure 34a shows a slide transmitted prior to the demonstration. Figure 34b shows the Premier leaving a car. Figure 34c shows the Premier addressing a banquet in his honor, and Figure 34d shows Premier Fanfani and Chicago's Mayor Richard Daley at a press conference. Received picture and audio material was reported to be excellent.

Figure 33. Public Demonstration, COMCON, Rev 207
(Received Signal Strength = −100 dbm)

Figure 34a. Public Demonstration, COMCON, Rev 285

Figure 34b. Public Demonstration, COMCON, Rev 285

Figure 34c. Public Demonstration, COMCON, Rev 285

Figure 34d. Public Demonstration, COMCON, Rev 285

IV. B. C. D. Narrowband Demonstrations

This demonstration confirms the two-way intercontinental telephony capability for the Relay satellite communications system.

The most recent two-way telephony demonstration was conducted between the United States and England during Rev 657 on March 9, 1963. The demonstration was conducted between COMHIL and COMNUT. The material consisted of an interview of American astronaut John Glenn in his home at Kemah, Texas, by Ronald Bedford, Science Editor of the London Daily Mirror. Transmission quality was reported to be good.

Other demonstration material that has been transmitted includes a taped message by Hugh Dryden, NASA Director, to Europe and South America, several narrations in Italian to COMTEL, and a USIA program to South America.

Successful transmission of facsimile pictures has been accomplished on a number of revolutions. Teletype messages have also been transmitted successfully on a number of revolutions.

V. SUMMARY OF RESULTS

Table 12 shows all experiments conducted between 5 January, Rev 175 and 8 March, Rev 658. During this period 105 revolutions were devoted to communications experiments. Approximately 550 experiments were performed during this time. Forty-six revolutions were used for narrowband (two-way telephony) tests and 56 revolutions for wideband (television and 300-channel telephony) tests. Some of the earlier revolutions were devoted to testing of both types of communication. Unfortunately, many of the experiments did not result in useful data. Equipment malfunctions, high noise levels and improper test procedures contributed to the loss of information.

Several effects characteristic of this type of satellite system have influenced the communications system performance. Tracking difficulties have caused occasional loss of signal during experiment performance, but in general, the tracking performance has been excellent. Spin modulation of received power has caused noticeable noise variations when the system operation was near receiver threshold. However, at signal-to-noise ratios which satisfy the system objective, no significant effect is indicated. Doppler shift makes the performance of any experiments requiring comparison of phase with a reference signal (differential time delay, differential phase) more difficult. COMAND has successfully generated a reference signal from the long-term average of the received signal, using phase-lock techniques. COMBOD has measured Doppler shift during Rev 332 (wideband or TV mode) and during Rev 471 (narrowband mode). During Rev 471 a measured shift of 24 kc was reported, compared to a calculated shift of 30.4 kc. The high noise level associated with operation at extreme ranges has made the performance of many tests impossible. Differential phase, delay measurements, noise loading measurements, intermodulation and intelligible crosstalk measurement have been affected by the noise level.

SYSTEM EXPERIMENTS	5 JAN	6 JAN	7 JAN	8 JAN	9 JAN	10 JAN	11 JAN	12 JAN	13 JAN	14 JAN	15 JAN	16 JAN	17 JAN	18 JAN	19 JAN	20 JAN	21 JAN	22 JAN	23 JAN	24 JAN	25 JAN	26 JAN	27 JAN	28 JAN	29 JAN	30 JAN	1 FEB	2 FEB	3 FEB	4 FEB
REV. NUMBER	175 176	182 183 184	191 192	199 200	206 207 208	214 215 216	221 222 223	229 230 231	236 237 238 239	245 246 247	253 254	259 260 261 262	267 268 269 270	275 276 277	282 283 284 285	292 293 294	299 300 301	306 307 309	314 315 316	322 323 324	330 331 332	336- 337 338 339	345- 346 347 348	352 353 354 355	361 362 363	370	383- 384	393	400	407
II. SYSTEM PERFORMANCE EXPERIMENTS - WIDEBAND																														
A. INSERTION GAIN STABILITY																														
1. Audio																									X					
2. Composite Video			X			X			X X X							X X			X		X X		X		X X	X			X	
3. Selective Fading	X	X																												
B. NOISE MEASUREMENTS																														
1. Continuous Random Noise - Video	X		X	X		X		X	X X X							X X		X	X	X	X X	X	X		X X	X			X	
2. Continuous Random Noise - Audio		X						X												X					X					
3. Impulsive Noise - Video			X			X		X	X X							X				X	X		X						X	
4. Impulsive Noise - Audio								X												X										
5. Periodic Noise - Video			X			X		X	X X							X				X			X						X	
6. Periodic Noise - Audio								X												X										
7. Fluctuation Noise			X			X		X	X X	X						X				X			X			X			X	
8. IF Noise and Interference																				X										
C. NON-LINEARITY DISTORTION																														
1. Line-Time Non-Linearity			X		X	X			X X							X X							X						X	
2. Synchronization Non-Linearity			X			X			X X							X							X						X	
3. Audio Distortion														X											X					
D. LINEAR WAVEFORM DISTORTION																														
1. Field-Time Distortion			X			X			X X							X	X				X		X X						X	
2. Line-Time Distortion			X		X X	X			X X					X		X X	X		X		X		X X		X	X			X	
3. Short-time Distortion ("2T" and "T" sine-squared pulses)			X			X			X X					X		X X	X				X		X X		X	X			X	
E. STEADY STATE CHARACTERISTICS																														
1. Bandpass Characteristics -- Baseband			X	X		X			X X	X				X		X X			X				X X						X	
2. Envelope Delay Distortion -- Baseband			X			X			X X	X						X						X	X						X	
3. Bandpass Characteristics -- RF																														
4. Differential Time Delay -- IF													X																	
5. Audio Amplitude Frequency Characteristic																									X					
F. RECEIVED CARRIER POWER	X X	X	X	X	X X	X	X	X	X X X	X X X			X	X	X	X X X	X X	X X X	X	X X	X X X	X X	X X	X X	X X	X			X	
G. SPECIAL TRANSMISSION TESTS																														
1. Baseband Doppler Shift																					X									
2. Absolute Delay																														
H. TELEVISION TESTS	X X	X	X	X	X X	X			X X X					X		X X X			X		X	X	X	X		X			X	
I. INTERMODULATION																														
1. Harmonic Performance																														
2. Cross Modulation Noise							X			X				X			X	X X						X						
III. SYSTEM PERFORMANCE EXPERIMENTS - NARROWBAND																														
A. INSERTION GAIN	X X	X	X	X		X X	X X	X X			X	X X X	X X	X	X X				X X	X		X		X			X	X		X
B. NOISE MEASUREMENTS																														
1. Continuous Random Noise	X X	X	X	X		X		X			X	X X			X							X		X			X			
2. Impulsive Noise																												X		
3. Periodic Noise																														
C. BANDPASS CHARACTERISTICS	X		X									X			X				X											
D. ENVELOPE DELAY DISTORTION																														
E. RECEIVED CARRIER POWER	X X	X	X	X	X	X X	X X	X X			X X	X X X	X X	X	X X		X		X X	X		X		X	X		X	X		X
F. INTERMODULATION																														
1. Harmonic Performance							X													X								X		
2. Noise Loading	X																		X									X		
G. ABSOLUTE DELAY																														
H. INTERFERENCE																														
I. CROSSTALK				X													X													
IV. SYSTEM DEMONSTRATION EXPERIMENTS																														
A. MONOCHROME TELEVISION					X										X															
B. DIGITAL DATA TRANSMISSION																														
1. Wideband Digital Data																														
2. Narrowband Digital Data																														
C. TELEPHONY																														
1. One-way Telephony																														
2. Two-way Telephony													X X	X					X			X			X					
D. COMPARISON OF RELAY AND OTHER COMMUNICATIONS CHANNELS																														
1. Teletype Transmission	X	X				X	X	X				X X	X X	X	X X				X			X					X	X		X
2. Facsimile Transmission					X	X		X											X											X
3. Wideband Teletype Transmission																														

-- STATION PARTICIPATION --																														
COMAND - ANDOVER	T T			T	T T T	T	T	T T		T				T T	T T		T			T T		T		T	T					
COMBOD - PLEUMEUR-BODOU				T T			T		T T			T	T					T T	T		T T			T T	T					
COMCON - NUTLEY (TEST STATION)			T			T			T T T					T		T T T			T		T		T T		T	T			T	
COMGER - RAISTING																														
COMHIL - GOONHILLY		T T			T	T		T			T T				R		T T T	T	T											
COMMOJ - MOJAVE (TEST STATION)																														
COMNUT - NUTLEY	T T	T	T	T		T T	T	T T			T T	T T T	T T		T					T		T					T	T		T
COMRIO - RIO de JANEIRO	R R		R		R	R	R			R		R		R R	T T R				T R	T		T R R		T		R				
COMTEL - FUCINO																														

NOTES:
- P = Primary Experiment
- X = Pre-correlation Experiment
- Y = Post-correlation Experiment
- √ = Monitored Experiment
- 0 = No mutual visibility during pass

LOOP THROUGH SATELLITE (15 JAN)

BAD DATA (29 JAN)

Table 12

Summary of RELAY Experiments, 5 January to 8 March 1963

DAYS AFTER LAUNCH	5 FEB	6 FEB	7 Feb	8 FEB	9 FEB	10 FEB	11 FEB	12 FEB	13 FEB	14 FEB	15 FEB	16 FEB	17 FEB	19 FEB	21 FEB	23 FEB	24 FEB	25 FEB	26 FEB	27 FEB	28 FEB	1 MAR	1 MAR	5 MAR	6 MAR	6 MAR	7 MAR	7 MAR	8 MAR	8 MAR
REV. NUMBER	416	423	430	440	447	454	463	471	478	486	495	502	511	525	540		565		580	587	595	602	603	634	641	642	649	650	657	658
II. SYSTEM PERFORMANCE EXPERIMENTS - WIDEBAND																														
A. INSERTION GAIN STABILITY																														
1. Audio																														
2. Composite Video		X				X	X						X				X													
3. Selective Fading																														
B. NOISE MEASUREMENTS																														
1. Continuous Random Noise - Video		X				X	X					X	X				X													
2. Continuous Random Noise - Audio																										X				
3. Impulsive Noise - Video																	X													
4. Impulsive Noise - Audio																														
5. Periodic Noise - Video					X												X							X						
6. Periodic Noise - Audio					X																			X		X				
7. Fluctuation Noise												X	X				X		X											
8. IF Noise and Interference																									X					
C. NON-LINEARITY DISTORTION																														
1. Line-Time Non-Linearity											X		X				X													
2. Synchronization Non-Linearity																	X													
3. Audio Distortion																														
D. LINEAR WAVEFORM DISTORTION																														
1. Field-Time Distortion																	X													
2. Line-Time Distortion													X				X													
3. Short-time Distortion ("2T" and "T" sine-squared pulses)													X				X													
E. STEADY STATE CHARACTERISTICS																														
1. Bandpass Characteristics -- Baseband												X					X		X								X			
2. Envelope Delay Distortion -- Baseband											X						X										X			
3. Bandpass Characteristics -- RF																														
4. Differential Time Delay -- IF																														
5. Audio Amplitude Frequency Characteristic																														
F. RECEIVED CARRIER POWER		X				X	X				X	X	X				X		X		X			X	X	X	X			
G. SPECIAL TRANSMISSION TESTS																														
1. Baseband Doppler Shift																														
2. Absolute Delay																														
H. TELEVISION TESTS		X				X	X						X				X									X				
I. INTERMODULATION																														
1. Harmonic Performance																														
2. Cross Modulation Noise																					X									
III. SYSTEM PERFORMANCE EXPERIMENTS - NARROWBAND																														
A. INSERTION GAIN	X		X							X				X						X										
B. NOISE MEASUREMENTS																														
1. Continuous Random Noise	X		X						X	X				X	X					X		X	X					X		X
2. Impulsive Noise									X						X							X	X							X
3. Periodic Noise									X						X								X					X		
C. BANDPASS CHARACTERISTICS																														
D. ENVELOPE DELAY DISTORTION																														
E. RECEIVED CARRIER POWER	X		X	X				X	X	X				X	X					X		X						X	X	X
F. INTERMODULATION																														
1. Harmonic Performance	X								X						X					X		X						X		
2. Noise Loading	X								X						X							X						X		
G. ABSOLUTE DELAY																														
H. INTERFERENCE																														X
I. CROSSTALK								X																						
IV. SYSTEM DEMONSTRATION EXPERIMENTS																														
A. MONOCHROME TELEVISION																														
B. DIGITAL DATA TRANSMISSION																														
1. Wideband Digital Data																														
2. Narrowband Digital Data																														X
C. TELEPHONY																														
1. One-way Telephony																														
2. Two-way Telephony			X	X										X																
D. COMPARISON OF RELAY AND OTHER COMMUNICATIONS CHANNELS																														
1. Teletype Transmission			X											X								X								
2. Facsimile Transmission			X											X															X	
3. Wideband Teletype Transmission																														
-- STATION PARTICIPATION --																														
COMAND - ANDOVER				T				T			T	T								T	T				T	T				
COMBOD - PLEUMEUR-BODOU					T			T		T									T					T						
COMCON - NUTLEY (TEST STATION)		T				T	T						T				T													
COMGER - RAISTING			T	T																										
COMHIL - GOONHILLY														T													T			
COMMOJ - MOJAVE (TEST STATION)																														
COMNUT - NUTLEY	T								T	T					T							T	T					T	T	T
COMRIO - RIO de JANEIRO																														
COMTEL - FUCINO	R	R	R						R											R									R	

NOTES:
P = Primary Experiment
X = Pre-correlation Experiment
T = Post-correlation Experiment
√ = Monitored Experiment
0 = No mutual visibility during pass

Table 12 (cont'd)

Summary of RELAY Experiments, 6 January to 8 March 1963

VI. CONCLUSIONS

In drawing conclusions from the data presented in this interim report, one must bear in mind both the quantity and quality of data available. First, considering the 105 revolutions during which communication experiments were conducted, the sampling of results here consititutes but a small fraction of the total data gathered to date. Much of the data was garnered from the daily Operations Summary Reports, because very few completed data forms were available from the participants. Naturally, these summary reports are far from complete with respect to reporting all of the test conditions. Furthermore, a disproportionate amount of data comes from the NASA test station at Nutley, N. J. (COMCON), because of its relative availability. This station does not have, and was not intended to have, the communications capability of the COMAND, COMBOD, and COMHIL stations, especially in regard to noise performance. All of these factors will have an effect on the validity and universality of the conclusions which follow:

Wideband Experiments

The results of the wideband communication experiments will be examined first. Among the series of tests for insertion gain and insertion gain stability (II. A. 1, 2, 3), the only reported results are for audio insertion gain (II. A. 1). Although the transmitted and received frequency deviations are in reasonable agreement, the corresponding power levels cannot be compared, because they are measured at different level points in the different stations. In the future, all participants should refer power measurements to a point of zero relative level, thereby facilitating comparison and insuring system compatibility. Of course, the establishment of the proper level in the baseband amplifiers has no bearing on the satellite performance, except as it may affect the frequency deviation.

Because no insertion gain stability measurements have been reported, it might be hopefully interpreted that phenomena such as selective fading are negligible at least with regard to observable effects at baseband.

The results of a number of video continuous random noise measurements (II. B. 1) were presented in Table 2. In terms of the 43 db weighted signal-to-noise ratio requirement of R1-0000, it can be seen that COMAND and COMBOD operate well above this minimum in the looped mode or when receiving from each other. However, when either of these stations or COMHIL receive from COMCON, the S/N ratio drops to about 40-45 db. Also, in loop COMCON achieves a signal-to-noise ratio between 30 and 40 db. COMTEL has observed S/N ratios between 19 and 42 db depending on the transmitting station and the range for the pass.

Table 3 shows a comparison between measured and predicted weighted video signal-to-noise ratios. When the actual received carrier power is used to predict the post-detection S/N ratio, the COMCON measured and predicted values are within 2 db of agreement in every case. The COMAND, COMBOD, and COMHIL results, on the other hand, are in much less perfect agreement. This may be due to less precise knowledge on the part of STL of the current operating parameters of the latter stations.

Although qualitative reports indicate satisfactory audio-channel performance, the continuous random noise measurement (II. B. 2) yields S/N ratios well below the objective of 50 db (unweighted) at both COMCON and COMHIL. The latter station measured a ratio of 35 db at a peak-to-peak deviation of 100 kc. Extrapolated to the system design deviation of 200 kc, the audio S/N ratio should improve to about 41 db at COMHIL. The reasons for the rather low S/N ratios in the audio channel are not known at the present time.

No reports have been received concerning impulsive and periodic noise in either the audio or video bands when the system is operating in the wideband mode. Again one might be tempted to conclude from this silence on the subject that such interference is negligible. Some results of periodic noise measurement made in the narrowband mode at COMNUT are reported below.

Experiment II. B. 7, Fluctuation Noise, seeks to measure the baseband noise spectrum, either continuously in frequency with a spectrum analyzer, or at discrete frequencies with a series of filters. Both techniques have been employed at COMAND and COMCON and have established that the noise spectrum is not triangular below about 300 kc in the baseband. This is probably due to noise from the system oscillators such as those that comprise the VCO of the phase-lock demodulator at COMCON. Another possible source of low frequency noise is the klystron oscillators used in the FM deviator. It has been determined at COMCON that misalignment of the deviator was degrading the overall S/N ratio by as much as 5 db. This difficulty was corrected just prior to Revolution 565; it may have contributed to poor S/N performance during some of the intermediate passes.

The nonlinear distortion measurements (II. C. 1, 2, and 3) pertain principally to baseband distortion and are not appreciably affected by spacecraft transmission deviations. Photographs of staircase signals at the line rate taken at COMCON and COMHIL show no evidence of line-time nonlinearity. Furthermore, differential gain as measured at COMCON is about $\pm$ 1 db. At COMCON, harmonic distortion measurements in the audio channel are hampered by the presence of noise in the measured spectrum. Allowing for the noise, however, it appears that audio distortion meets the system requirement of 2%. Steps are presently being taken to eliminate the noise from the distortion measurement.

The class of linear waveform distortions (II. D. 1, 2, and 3) also belongs in large measure to the baseband equipment rather than to the satellite. A number of measurements of field, line and short-time distortions at COMCON and COMHIL have verified that system objectives have been met. Some deficiencies in the field-time waveforms (Figure 7) taken at COMCON are attributable to the use of a poor black-and-white test slide and known baseband amplifier vagaries. Line-time photographs (Figures 8 and 9) show that overshoot, ringing, and tilt are within system objectives. The ringing is at the rate determined by the sharp cutoff 3.2 mc low-pass filter following the demodulator.

Corresponding to the transient responses to the field bar and T-pulse signals are the system steady-state responses such as overall baseband gain and phase characteristics. COMAND has directly measured the gain-or amplitude-frequency characteristic (II. E. 1, Figure 13). The most interesting feature is a 0. 2 db hump in the characteristic between 2. 5 and 4 mc, which is attributed to the spacecraft. No degradation of picture quality should result from this feature, however. COMBOD has measured the audio channel amplitude-frequency characteristic (II. E. 5) and found it to be essentially within specification.

Although no baseband delay distortion measurements have been reported, differential time delay (II. E. 4) at intermediate frequency has been measured at COMAND and COMBOD. The results are reported in different terms, but appear to be in basic agreement. The operational measurements are also consistent with the pre-launch test results on the spacecraft (Table 4). When the measured nonlinear delay components are converted to their equivalents in psophometrically-weighted noise power, the results are well within the system requirement of 7500 pw total. A direct correlation of measured intermodulation noise with that predicted from delay measurements can be carried out after further data becomes available.

Considerable data concerned with received carrier power (II. F) has been gathered. Maximum and minimum values and typical variation are presented in the body of the report. Measured and predicted values of received power agreed fairly well except for the results reported by COMCON. The problem at the test station seems to be that the parametric amplifier gain varies with antenna attitude. Therefore, gain calibration of the system prior to spacecraft acquisition is of no value once the antenna begins to track the satellite. However, the varying gain affects both signal and noise, leaving the S/N ratio relatively unaffected. Thus, excellent agreement between measured and predicted S/N ratios (II. B. 1) can be obtained even though the results for received carrier power cannot be reconciled.

A comparison of measured and predicted signal strength received at the spacecraft suggest that the telemetry calibration is high by at least 3 db. Also a comparison of COMAND and COMBOD results with those of COMCON indicates that COMCON has had some tracking difficulties during some of the passes. Generally, however, tracking performance has been excellent.

Several reports of phenomena associated with spin modulation have been reported. Variations in received power have ranged from 2 to 8 db and the reported spin rates lie between 150 and 166 rpm. The data agree well with the spacecraft antenna gain pattern. When the signal is near threshold, the amplitude fluctuations due to spin are accentuated by the steepness of the input-output S/N characteristic. The effect can be quite annoying both visually and aurally.

A large number of television test patterns and picture material (II. H. 1) have been transmitted through the Relay system. Multi-burst signals, EIA test patterns, cross and black window patterns, and typical picture material all show excellent quality as received at COMHIL (Figures 22 through 25). As a quality comparison between the better ground stations, a series of photographs of material received at COMCON and COMMOJ is included (Figures 26 and 27). The conclusion can be drawn that even these stations can produce acceptable 525 line standard TV pictures while the better stations are capable of excellent video reproduction. The pictures received during wideband demonstration experiments (IV. A) also bear this out.

The results of intermodulation noise tests (II. I. 2) from COMBOD and COMHIL are reported. It is difficult to compare the values obtained. One measurement was made with 300 channel loading and the other with 600 channels at an increased deviation, so that the intermodulation noise could be distinguished from thermal noise. The former test gave large values of IM noise and the latter very large values, as would be expected. Neither set of data correlates well with the pre-launch test results nor with the values predicted from the differential time delay measurements. Clearly much better data is needed in this important area of the communication experiments.

Narrowband Experiments

Insertion gain measurements (III. A. 1) in the 12 channels of a group have been performed numerous times. The insertion gain is highly variable when the test is performed in straight-away between stations. In loop, of course, the gain approaches the specified 0 db more closely. Insertion gain variations have generally been held to $\pm$ 1 db in accordance with R1-0000. An interesting unexplained feature of the gain measurements has been a periodic variation of the tone level at 1.0 - 1.5 cps.

Continuous random noise measurements in the narrowband mode (III. B. 1) have generally met system objectives. Typical results from COMBOD, COMHIL, COMNUT, and COMTEL are given in Table 8. The values reported by COMBOD appear to be in error because this is a high-quality station which should easily meet the 7500 pw objective. Reported measurements from COMBOD for other revolutions also tend to be high.

Only one measurement of periodic noise has been reported. On revolution 393 COMNUT found a minimum signal-to-noise ratio of 56 db which compares favorably with a 50 db requirement. No evidence of impulsive noise has been reported.

Baseband amplitude frequency response characteristics (III. C) have been measured between COMNUT and COMTEL and for COMNUT in loop. The response is flat to within 0.3 db from 12 kc to 108 kc, the band of interest. No baseband delay distortion tests (III. D) have been reported, so similar information about the phase characteristic is not available. Of course, both gain - and phase-frequency characteristics are primarily a function of the baseband equipment rather than the r-f and i-f circuits either on the ground or in the spacecraft.

Narrowband intermodulation tests (III. F) employing both noise and tone loading have been conducted. COMAND, COMNUT, and COMTEL have placed two tones in different telephone channels and measured the intermodulation products which fall in the rest of the channels. No direct specification on the allowable levels of these products has been established for

Project Relay. However, these results can be related to the noise-loading tests. This will be done in a subsequent report.

Intermodulation noise (III. F. 2) measured by noise loading at COMNUT is considerably higher than the objective of 7500 pw. The noise peaks in the middle channel, which is not surprising in a pre-emphasized system. Some results obtained when COMNUT transmitted to COMTEL showed the intermodulation noise to be well within specification. The difficulty, therefore, appears to be in the COMNUT receiving equipment.

Intelligible crosstalk (III. I. 1) may result from the interactions of the two narrowband carriers in the spacecraft or ground common r-f and i-f equipment. The measured results have been highly variable, ranging from a level of -36 dbm0 to -55 dbm0, the system objective. The pre-launch measurements on the spacecraft gave a value of -41 dbm0. If complementary channel operation is employed such levels are probably permissible, although generally the -55 dbm0 specification must apply.

To sum up the communication experience with Relay to date, one can say that operational results have generally been quite satisfactory. The paucity of experiment data forms has precluded a thorough evaluation of the system. However, data on linear and nonlinear distortion indicates the system meets the objectives. Thermal noise is essentially as predicted except in a few instances. Direct measurements of intermodulation noise are above objectives but the differential time delays are in compliance with the requirements. Further data is needed here. Television transmission between the better ground stations is of excellent quality. A number of both wideband and narrowband demonstration experiments have been successfully performed.

In the area of experiments which are especially sensitive for a satellite communication link, the received carrier power and S/N ratios are in substantial agreement with predicted values when all of the experimental circumstances are considered. Some anomalies have, of course, been discovered. Unfortunately no data has been reported concerning baseband doppler shift and absolute delay. Also whether baseband envelope delay measurements have been successfully made is not known. Hopefully, those tests which are inadequately represented will be made in the near future and can be discussed in the next interim report.